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REFERENCE

Lane, B. H., 1935, Suggestions to authors of papers submitted for publication by the United States Geological Survey: U. S. Geol. Survey, Washington, D. C. (For sale by Superintendent of Documents, Washington, D. C. 35c.)

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American Journal of Science

JUNE 1955

A REINVESTIGATION OF THE HISTORY OF LOWER LINSLEY POND, CONNECTICUT

J. R. VALLENTYNE and YVONNE S. SWABEY*

ABSTRACT. A new profile from Lower Linsley Pond is described. The sediment column has four distinct regions, a basal zone of gravel, followed by silt-clay, then banded gyttja, and finally unbanded gyttja. Pollen analysis shows essentially the same trends as given for a similar profile by Deevey. The zone of banded gyttja is shown to contain a series of alternating brown and black bands, comparable in thickness to microdistal varves. Using the counts for brown bands in conjunction with known radiocarbon dates, the age of the oldest organic sediments in the lake is computed to be 11,500 years. This date is considered to be identical with that of the Two Creeks Interval. Reasons are presented to suggest that inorganic sedimentation was rapid during the early phase of the lake's history, and that the age of the lake is little, if any, beyond 12,500 years. Thirty-four levels of the profile were quantitatively analyzed for the following microfossils: *Plumatella* statoblasts, *Bosmina* heads and shells, higher plant fragments, black spheres (nature unknown), supposed suctorian cysts, and disc-shaped structures called wheels (identity unknown). Data on ignitable matter and sedimentary chlorophyll were determined from a larger number of levels. A zone characterized by a high ratio of *Bosmina* heads to shells was found in sediments of the middle C1 pollen zone. The occurrence of an excess of heads could have been caused by either breakage or selective transport by currents, and there was experimental evidence in favor of both concepts. Since breakage, turbulence and secondary deposition are probably inseparable factors, the hypothesis was advanced that the rate of secondary deposition was increased in middle C1 and resulted in breakage and a redeposition of shallow water forms in deep water. This accounts for the presence of epiphytes in C1 sediment levels much deeper than the greatest depths at which the epiphytes now live in the same lake. The breakage zone appeared to be coeval with the First Major Disturbance Zone described by Patrick for the sediments of Linsley Pond. This zone was characterized by extensive breakage of diatom tests. Breakage in *Plumatella* statoblasts and pine pollen grains increased from low levels in the lower C1 pollen zone to a maximum in the middle of the C1 pollen zone, but breakage remained at a fairly high level thereafter.

A comparison of the quantitative values for sedimentary chlorophyll and higher plant fragments on a percentage basis led to the suggestion that the sedimentary chlorophyll was primarily derived from the phytoplankton in all time subsequent to middle C1. New data are presented for CaO and MgO at 31 levels of the profile, and it is clearly shown that there is no rise in the CaO/MgO ratio in middle C1 as might be expected if the water level had dropped during that time.

All published data on the sediments of Lower Linsley Pond are interpreted in terms of three hypotheses which attempt to explain the high numbers of epiphytes in deep water during the C1 pollen zone. The hypotheses of lower water level and of increased transparency are rejected in favor of the hypothesis of increased secondary deposition which accounts for the zone of breakage in middle C1; since objections to this are not considered to be so serious as those for the other two, this hypothesis is accepted as giving the best explanation of the facts now known.

INTRODUCTION

During the past three years the senior author has attempted to develop a biochemical approach to paleolimnology, based on the amounts and types of chlorophyll degradation products and carotenoids in sediments deposited at various times during the development of a lake (Vallentyne, 1954). During

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the course of this work it was realized that a good approach would be to make a thorough study of these biochemical fossils in the sediments of a lake that had been well characterized by more classical methods of paleolimnology. Lower Linsley Pond, North Branford, Connecticut was selected for that purpose. The pond is located about four miles NE of New Haven, Connecticut, at an altitude of 25 m above sea level. The present-day biology of Linsley Pond[1] has been studied by Riley (1940). The physics and chemistry of the lake have been studied by Hutchinson (1938, 1941), Hutchinson, Deevey, and Wollack (1939) and Hutchinson and Bowen (1947, 1950). Sediment profiles from the lake have been analyzed for pollen by Deevey (1939), animal microfossils (Deevey, 1942), diatoms (Patrick, 1943) and chemical constituents (Hutchinson and Wollack, 1940).

During the course of the work on sedimentary pigments, we came to a different interpretation of the lake's history than that held by previous workers (Deevey, 1942; Patrick, 1943). Our interest was therefore temporarily deflected from the pigment content of the sediments to the history of the lake.

The central problem to be explained is the occurrence of an epiphytic biota in sediments deposited in the middle of the C1 pollen zone at a site 24 meters below the present water surface. Since rooted vegetation does not extend much below 5 meters depth in Linsley Pond at the present time, it is clear that one of three hypotheses could explain the deeper occurrence of rooted vegetation in C1:

(1) Low water level in middle C1.

(2) High transparency in middle C1.

(3) Increased secondary deposition in middle C1.

Evidence against a low water level was presented by Deevey (1942). Deevey seemed to favor a combination of the second and third hypotheses, but laid most stress on the hypothesis of high transparency. Our interpretation is that the third hypothesis is correct. The purpose of this paper is to document the hypothesis of secondary deposition and to show that the other two hypotheses are untenable because of the lack of primary evidence in favor of them. In addition, new data are presented for the lake.

ACKNOWLEDGMENTS

We are indebted to D. A. Livingstone of Dalhousie University, Halifax, Nova Scotia, who volunteered his help and equipment in obtaining the new profile. H. Ignatius, now of the Finnish Geological Survey, analyzed the new profile for pollen. For expert criticism and advice we acknowledge the help of E. S. Deevey, Jr. and G. Evelyn Hutchinson, both of Yale University, New Haven, Connecticut. The work on plant and animal microfossils was made possible by a grant from the National Research Council of Canada. Part of the work reported here was presented to the Graduate School of Yale University as a thesis in partial fulfillment of the degree of Doctor of Philosophy.

[1] Lower Linsley Pond is commonly referred to just as Linsley Pond. We use these names interchangeably throughout. To avoid confusion, the adjoining upper pond is always called Upper Linsley Pond.

METHODS

The new profile (hereafter referred to as the LV profile, in consistency with Deevey's nomenclature) was obtained in December, 1952 from a raft anchored over 14 meters depth of water. The Livingstone piston sampler (Livingstone, 1955) was used to collect the sediment. Sediment depths are all given as meters below the present water surface. Sediments from 15.0 to 22.0 m (LV) were collected with a piston sampler of 17 mm inside diameter. All deeper sediments were collected with a piston sampler of 36 mm inside diameter. The larger sampler was found to be the more useful. Samples for two intervals (16.5-17.0 m and 22.0-22.5 m) had to be discarded because the sampler opened prematurely. Time did not permit us to sample those depths at adjacent sites, and data are therefore lacking for those intervals. The small piston sampler was designed to take samples 50 cm in length; however, the actual samples varied from 35 to 48 cm in length; likewise with the larger sampler which was designed to take a sample 100 cm in length. When we adjusted the piston line for the next sample we assumed that the previous tube was completely full. It will be clear that we do not have a complete profile.

All samples were kept in their aluminum tubes for one and a half months at 4°C. before they were opened. Samples were extruded into half cylinders of sheet aluminum and enclosed in polyethylene bags. We have no estimate of the compression which occurs when the mud is forced from the tube. No preservative was added to the sediments at any time; however, they were always kept in a cold room at 4°C., except when transported. One sample accidentally left at room temperature overnight developed a bluish sheen on the surface. The color appeared to be caused by the presence of cocci-type bacteria. All analyses for organic chemicals were completed within two months of the opening of the tubes. Visible fungus and bacterial growth, with the exception of the instance cited above, did not appear until 10 months after the opening of the tubes.

Samples for chemical or microfossil analyses were taken over a vertical distance of at least 1 cm, representing deposition over a period of at least 10 years. Annual variations in the deposition of fossils do not appear in our results. Differences in the concentration of any particular compound or fossil between two levels must be taken as minimal.

The method of analysis for sedimentary chlorophyll is that given by Vallentyne (1955) except that dimethyl aniline was not added to the acetone used in extraction. The percentage ignitable matter was determined by measuring the percentage loss of weight on ignition (Bunsen burner for 15 minutes) of a sample dried at 100°C. for 20 hours. Linsley Pond sediments are not calcareous except near the 27 meter level, and the ignitable matter probably corresponds closely to the organic matter content, except in the inorganic zones where the clays may hold inter-lattice water tenaciously at 100°C. Analyses for CaO and MgO were done in the spectrographic laboratory of the Geology Department of Queen's University.

In order to make quantitative microfossil counts we adopted the following procedure: The sample for analysis was homogenized on a glass plate

until of even consistency. An aliquot was removed for the determination of water content (oven-dried at 100°C. for 20 hours); knowing the water content and the wet weight used for analysis, we could determine the dry weight used for analysis. For all quantitative microscopic counts, a 500 mg sample (wet weight) was boiled for 15 minutes in 10 percent KOH in order to loosen the sediment particles. The sample was centrifuged to remove the KOH and then suspended in 50 ml of distilled water. The suspension was thoroughly mixed before each aliquot was removed. Counting was done in a standard Sedgewick-Rafter counting cell. Quantitative counts were made of: leaf and stem fragments, black spheres, *Bosmina* heads, shells of Cladocera, statoblasts of *Plumatella*, and two structures of unknown identity which we shall refer to as suctorian cysts (after Deevey, 1942) and "wheels." In order to have significant statoblast counts the entire 500 mg sample was scanned for statoblasts. Counts of all other structures were made on three Sedgewick-Rafter counting cells and the results averaged. The arbitrary method adopted for counting higher plant fragments was to count the number of squares on an ocular micrometer which the plant fragment covered. The relative scale for these fragments is therefore squares cut per unit weight of sediment. The microscopic counts had an error of about 20 percent at levels where the numbers were low. This error was reduced when the numbers counted were high.

All pollen counts were based on a minimum of at least 100 grains. Although it is preferable to count a larger number of pollen grains, we do not

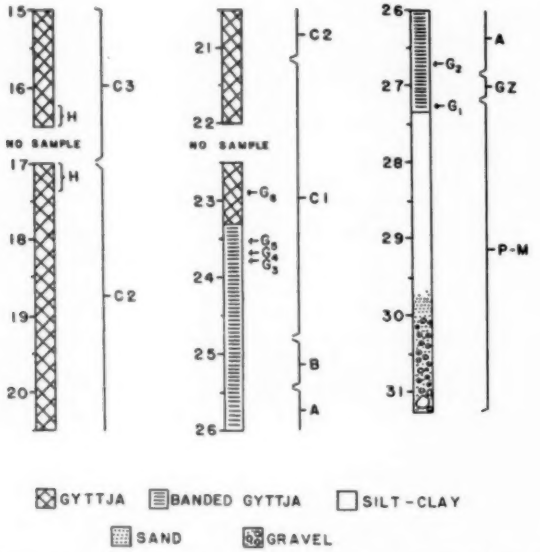

Fig. 1. Gross description of the LV profile. G_1-G_6 refer to gritty layers; GZ to Gray Zone; H to sediment levels which had a rock-like hardness when dry; and P-M to sediments considered to have been deposited in pre-Mankato time.

feel that the analyses are greatly in error. Our results differ little from those of Deevey (1939) for his L-10 profile in the same lake.

Other methods used in the analysis of the core are of a specific nature and will be dealt with in the description of results.

GROSS DESCRIPTION OF THE LV PROFILE

This profile was taken beneath 14 m depth of water. The first meter of sediment was sampled with an Ekman dredge. Sediment collected with the Livingstone sampler extended from 15.0 to 31.25 m depth. The failure to take samples below 31.25 m was due to the gravelly nature of the deposit. Some stones were actually the diameter of the sampling tube. It was possible to push a probe to 33.0 m, but the probe broke at that depth, and we are unable to say how much further it might have penetrated. In figure 1, a graphic description of the profile is presented. Four macroscopially distinct regions were noted:

(1) Gravel and sand, 31.25-29.80.
(2) Silt-clay, 29.80-27.35.
(3) Banded gyttja, 27.35-23.30.
(4) Unbanded gyttja, 23.30-14.00.

The junctions between these regions showed gradual changes and do not suggest time discontinuities in sedimentation. The term clay is used to indicate particle size rather than mineral components. Gyttja is used here to mean an organic sediment mostly composed of plankton remains.

The zone of gravel and sand showed a change from gravel at the bottom to coarse sand, then fine sand at the top. Two slanted bands of silt-clay were found in the sand region (30.100-30.036 m and 29.979-29.967 m). The gravel at the bottom of the profile was examined by R. F. Flint of Yale University who was of the opinion that the gravel was either a till or else a solifluction deposit.

The zone of silt-clay contained 16 bands of coarser sand-sized particles. The alternating bands of silt-clay and sand may represent varves (used here to mean an annual cyclic deposition). If this is true (there is no primary evidence to indicate that this is so), then this thickness of sediment (2.4 m) was deposited in 16 years.

The zone of banded gyttja was gray-brown in color at the bottom but gradually changed to a dark brown-black color at the top. The banding consisted of a series of light brown bands which alternated with black bands. At the top and bottom of this zone were regions where the brown bands could be seen but were too poorly defined to permit counting. At six places in the zone of banded gyttja there were dark areas which contained small but significant amounts of large silt-sized grains. These are called gritty layers and are numbered g_1 to g_6 in chronological order. The gritty layers showed no distortion in banding as might be expected if they were the result of some catastrophic event.

When the tubes of banded gyttja were first opened there could be seen large areas of dark sediment alternating with large and lighter (browner) areas. These were especially prominent at depths below 25 m. On close examination it could be seen that the large dark areas were composed of

alternating brown and black bands in which the latter predominated, whereas the large light areas were composed of alternating brown and black bands in which the former predominated. The vertical distances of these large areas tended to be approximately equal, each having a vertical thickness of 1-2 cm on the average. After the sediment had stood in contact with air for a few weeks these areas could scarcely be distinguished. It is probable that future work on these areas will reveal fluctuations in the pattern of sedimentation. Our observations are given here only to point out the presence and instability of the large bands.

The zone of unbanded gyttja was jet black in color throughout and showed no conspicuous features which could be used as landmarks. The gyttja was composed of fine-grained particles united in a gel-like matrix. The levels denoted by "H" in figure 1 characteristically dried to a rock-like hardness. This peculiarity was not noted at other levels.

Pollen zones are used to divide the profile into sections. In the A pollen zone, however, the Gray Zone was such a conspicuous landmark that it became useful in subdividing the A pollen zone. If our interpretation is correct, the Gray Zone corresponds to the time of the Two Creeks Interval (roughly 11,000 years).

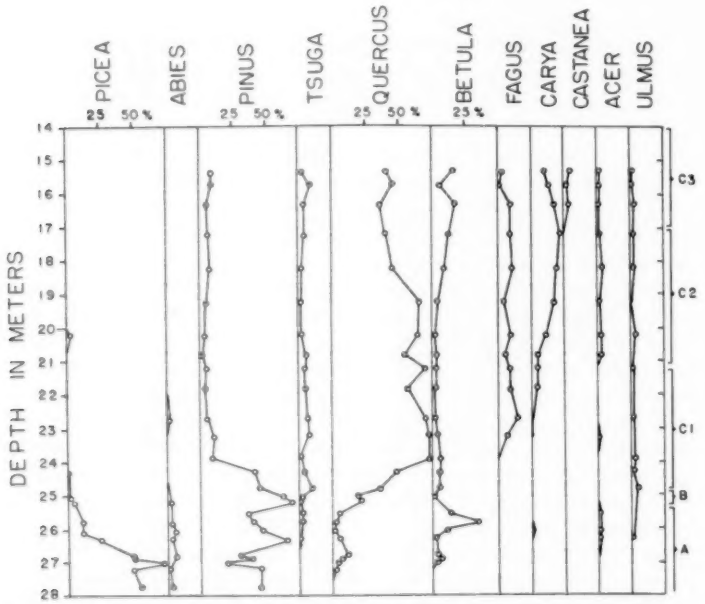

Fig. 2. Pollen zonations in I.V profile. Relative abundance of each genus is expressed as a percentage of the total pollen count.

POLLEN ANALYSIS

The results of pollen analysis are shown in figure 2. There is essentially no difference between our results and Deevey's (1939) for any of the C zones. There is a B zone (pine pollen) present in the LV profile and also a slight increase in oak pollen at 27.0 m depth, an increase which is perhaps not significant. The absence of the B zone in Deevey's L-10 profile is due to the fact that his samples were interspaced too far. The slight increase in oak pollen at 27.0 m may indicate a time when the climate was warmer than immediately before or immediately after. Deevey (1951) found high numbers of grass and sedge pollen grains below the A zone in Maine lakes, designating the grass pollen zones as L-1, L-2 and L-3. Only arboreal pollen grains were counted in the LV profile. Deevey and Potzger (1951) have shown that Deevey's A zones in Connecticut need revision.

BROWN BANDS

The brown bands of the banded gyttja, together with the alternating black bands, are comparable in thickness to the microdistal varves which Pennington (1947) described in the sediments of Windermere. Pennington noted that each of the microdistal varves was subdivided into a series of two or three pairs of smaller bands. She counted only the large bands which could be seen on direct examination. We have found in dealing with the Linsley Pond bands that it is impossible to count the number of macroscopic bands without introducing an error that varies widely with the observer. After being shown what was meant by a large band (comparable to those counted by Pennington), four observers produced counts for one section of the profile which ranged from 16 to 35. When the same observers were given a magnifying glass and asked to count all the bands which could be seen the counts became reproducible to within 10 percent. For consistency we felt it advisable to count all the bands.

The method of counting was as follows: The mud surface was scraped with a smooth-edged spatula, parallel to the banding, until the surface was flat and smooth. A large hand lens was used and the bands were counted by viewing the mud tangentially to the scraped surface. The number of brown bands was counted over a vertical distance of 2 cm, and the number for three separate counts averaged to give the mean number of brown bands per cm. The mean of three counts usually deviated less than 5 percent from the extremes.

Throughout the zone of banded gyttja the average number of brown bands per centimeter was 31. A detailed microscopic study of the banding will be the subject of a later communication. It is worth noting here, however, that the largest brown bands are extremely rich in diatom tests and have the consistency of diatomaceous earth when dry. The black bands appeared to contain a larger proportion of humic material than the brown bands.

If the system of banding described above was due to seasonal sedimentation differences, it should be possible to use the information on band counts to construct a chronology for the sediment profile. Figure 3 is a graph relating the number of brown bands per cm to depth. The general decrease

from 40 brown bands per cm at the bottom to 25 per cm at the top suggests either greater compression of the lower sediments or else a decrease in the amount of sediment deposited with time. Probably both factors are involved.

Two methods of regression analysis were used in order to obtain a date for the 27.0 m level. For each method, three assumptions are involved:

(1) That the average number of brown bands deposited per year has been constant for the entire zone of banded gyttja. We are concerned only with the average, and not with particular values in any year.

(2) That the missing parts of the profile have approximately the same number of brown bands per cm as the adjacent regions which we collected.

(3) That extrapolation of the linear regression lines from the zone of banded gyttja to the C1-C2 boundary is permissible.

Assumption 1 is probably not strictly correct, but may be to a first approximation. We have no way of testing assumptions 2 and 3, but on the other hand there are no data which contradict these assumptions for this lake.

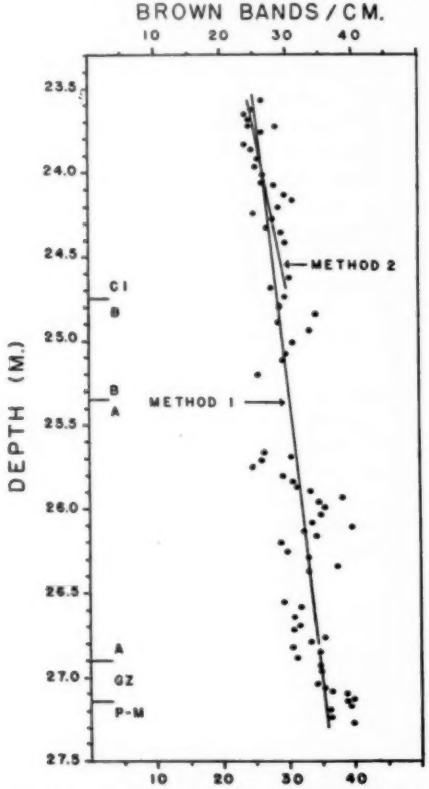

Fig. 3. Number of brown bands per cm plotted against depth. Method 1 (see text) used to derive the regression line for all points shown. Method 2 used to derive the regression line only for points in the C1 pollen zone.

Method 1 was to derive the straight line of best fit for all the points shown in figure 3. The regression equation is:

$$Y = 2.89X - 43.0$$

where the units of Y are brown bands per cm, and the units of X are depth in meters. The regression line was extrapolated to the C1-C2 boundary at 21.1 m. The theoretical number of brown bands deposited during C1 was determined graphically and divided by the difference between the C^{14} ages (Flint and Deevey, 1951) for the top and bottom of the C1 period, i.e. 8323 years (B-C1) minus 5159 years (C1-C2). This gives a figure for the rate of brown band deposition during C1, the value being 2.65 brown bands per year. By graphically summing up the number of brown bands deposited during three earlier periods in the lake's history (area under the regression line), it was possible to obtain values for the durations of those periods in terms of years. These data are summarized in table 1.

Method 2 was to derive the straight line of best fit for only the brown bands in the C1 pollen zone. The regression equation is:

$$Y = 5.02X - 93.91$$

where the units of Y and X are those given above for Method 1. The regression line was extrapolated to the C1-C2 boundary. The theoretical number of brown bands deposited during C1 was again determined graphically and divided by the duration of the C1 zone as determined by C^{14} dates. By Method 2 the rate of brown band deposition during C1 was 2.42 bands per year. By graphically summing the brown bands for earlier periods (area under the connected points), values comparable to those obtained by Method 1 were derived. These data are given together with the corresponding data for Method 1 in table 1.

TABLE 1

Brown Bands, Durations and Ages of Zones during the Early History of Linsley Pond

Ages given as years before 1950 A. D. Dates by Method 1 not in parentheses. Dates by Method 2 in parentheses.

Zone	Brown Bands	Duration (yrs.)	Age of lowermost boundary
C1	8394	3164	8323
	(7665)	(3164)	(8323)
B	1762	664	8987
	(1710)	(706)	(9029)
25.35 to 27.0 m	5384	2029	11,016
	(5052)	(2085)	(11,114)
27.0 to 27.28 m	987	372	11,388
	(1045)	(431)	(11,545)

An examination of table 1 shows that the two methods yield results which are not greatly different. The age of the 27.0 m level was found to be slightly over 11,000 years, i.e. identical in time with the radiocarbon dates for the Two Creeks Interval in North America and the Allerød in Europe. One other fact supports the suggestion that the 27.0 m level was coeval with the Two Creeks Interval: the sediments at the top of the Gray Zone are enriched in $CaCO_3$, as will be shown below. The L2 zones described by Deevey (1951)

for lakes in Maine also have a high $CaCO_3$ content, and the L2 zone is probably contemporaneous with the Two Creeks Interval, as Deevey suggested.

A second point worthy of note is that the age of the oldest sediments in the zone of banded gyttja does not exceed 11,500 years on our calculations. With due allowance for the error in radiocarbon dates and over-allowing for the 16 varves (?) in the silt-clay zone, we are of the opinion that the origin of Lower Linsley Pond occurred very little, if any, earlier than 12,500 years ago. This suggests that the Linsley Pond till is of Cary, not Tazewell, age.

It is appropriate here to remark on previous estimates of the age of Linsley Pond. Hutchinson and Wollack (1940) constructed two relative time scales, one on the assumption of a deposition of a unit volume of sediment in a unit time, and the other on the assumption of a deposition of a unit weight of ash in a unit time. Hutchinson and Wollack thought that the truth lay between these two extremes. While this is undoubtedly correct for the organic sediments of Linsley Pond, it must be in error if extrapolated to the early inorganic sediments.[2] In both assumptions the time calculated for the deposition of the silt-clay zone would be far greater than was actually the case. During this time erosion must have proceeded at a rapid rate, and both a unit volume of sediment and a unit ash would be deposited at a faster rate than in subsequent time. If our interpretation of varves (?) in the silt-clay zone is correct, then the average rate of deposition in that zone was 15 cm per year as compared to 0.8 mm per year in the banded gyttja zone. The former value seems much too high.

Deevey (1942), using three different sets of assumptions, computed three different ages for the middle of the C1 pollen zone. These calculations were made from counts of fossil *Bosmina* in the L-10 profile, using some rather uncertain values for the annual turnover rates for *Bosmina* in present-day lakes. The most probable age selected was 11,300 years. Recently, Deevey (1955) has computed estimates for the age of the oldest sediments in his L-10 profile on the basis of unit *Bosmina* deposition and unit ash deposition per unit time, using these assumptions in conjunction with the known radiocarbon dates at higher levels. The estimates proposed are 16,000 years (*Bosmina*) and 26,000 years (ash). The ash time scale has been discussed above. It will be shown below that some of the *Bosmina* remains in the L-10 profile were redeposited secondarily from shallow water, and hence the *Bosmina* time scale will give an older age for the lake than is actually the case.

[2] Hutchinson and Wollack (1940) state in a footnote: "If it be objected that assumption 1 [unit volume in unit time] still does not allow enough sedimentation of clay and silt per unit of time in immediate post-glacial times, it must be supposed that productivity has declined since the 40 foot level [inorganic sediments of the L-10 profile]."

We disagree with this statement. In a unit volume of sediment in the organic part of the profile, 50 percent of the dry weight is organic matter, whereas in the inorganic section the organic matter probably composes 1 percent or less of the dry weight. If the rate of unit volume deposition were ten times greater in the inorganic section than in the organic, this would still permit a fivefold increase in organic productivity in later time.

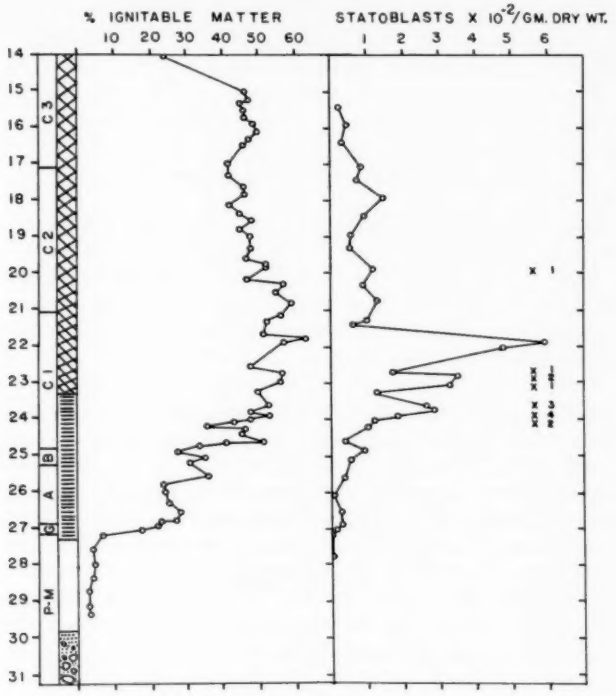

Fig. 4. Percent ignitable matter and *Plumatella* statoblasts plotted against depth. Points at the right refer to sediment levels where "wheels" were found. The numbers opposite each X refer to the number of wheels in 0.5 g of wet mud. Sediment zonations as in figure 1.

IGNITABLE MATTER

Data for ignitable matter are shown graphically in figure 4. The general trend of the curve is essentially the same as that given by Hutchinson and Wollack (1940), i.e. rising from low values in the oldest sediments to a maximum in C1, and showing a pronounced drop at the surface. On closer inspection, however, several differences are revealed. Hutchinson's curve shows a sigmoid increase from the oldest sediments to the C1 maximum. The initial rise in our curve is abrupt and reaches an early maximum at 26.8 m. Between this maximum and the upper C1 maximum there occur three well-defined minima, at 25.80, 24.90 and 24.20 m respectively. The minima represent an increase in the relative rate of inorganic sedimentation. If the increase in ignitable matter is interpreted as being sigmoid, one should realize that there are major departures from the true sigmoid curve.

If our interpretation is correct, that the 27.0 meter level was deposited during the Two Creeks Interval, then the increased ignitable matter found at this level may have been associated with warming of the climate.

PLUMATELLA

Figure 4 also shows the number of statoblasts of the freshwater bryozoan *Plumatella* (per g dry weight) at various levels of the profile. The general trend of this curve differs little from that given by Deevey (1942) for statoblasts in the L-10 profile. One major point of difference however is that our data show three separate and distinct maxima in C1, not a single maximum as Deevey found. Each of these three maxima is associated with high ignitable matter content.

The interpretation of statoblast counts formed a major basis of Deevey's transparency hypothesis. *Plumatella* is generally found in shallow water, often growing epiphytically, and it was primarily the marked C1 maximum which prompted Deevey to postulate high transparency at that time. A discussion of this interpretation will be deferred until counts for *Bosmina* in the LV profile have been presented.

WHEELS

Between the depths of 24.0 and 22.5 m wheel-shaped organisms or parts thereof were found. A photograph of one of these is shown in figure 5. Although a number of authorities have been consulted, we do not yet have a positive identification and will simply refer to these forms as wheels since they show resemblance to a bicycle wheel. Their diameter is variable. We have found specimens ranging from 100 up to 350 microns in diameter. The shape is always that of a disk circular in outline.

The interesting point about the wheels is that they have been found, with one exception, only in the 24.0-22.5 m interval, as is shown in figure 4. This is the same interval as that in which *Bosmina* remains appear to have

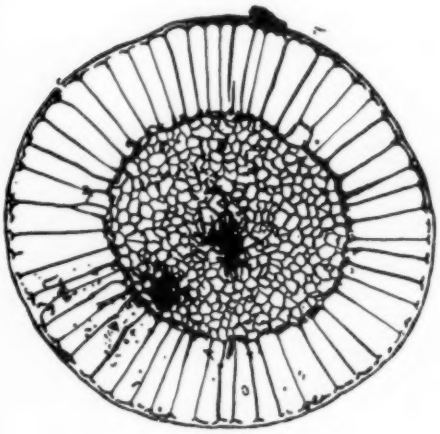

Fig. 5

Fig. 6

Fig. 5. Photograph (retouched) of a "wheel." The diameter varies from 100 to 350 microns.

Fig. 6. Photograph of black spheres. Note the spherical structure. Diameter is variable, but averages about 10-15 microns.

been secondarily deposited in deep water (see below), and this relationship suggests that the same may be true of the wheels.

BLACK SPHERES

The small spherical bodies shown in figure 6 we will call black spheres. The average diameter of these spheres is about 10-15 microns; however, there is much variation. The black spheres resist boiling in concentrated HCl, but after oxidation with 30 percent H_2O_2, the spheres turn orange and can then be dissolved by boiling in concentrated HCl. Boiling in either water or 10 percent KOH does not affect the numbers found. These facts suggest that the black spheres are concretions of ferrous sulfide (Naumann, 1930). The spheres are evidently formed around nuclei, but we have so far been unable to find out what the nuclei are. In a preliminary examination of the profile the numbers of black spheres were noted to vary from level to level. For this reason we decided to count them quantitatively, even though we did not know how to interpret the results. The data are shown graphically in figure 7. The only observation we wish to make is that the numbers are roughly constant above the 27 m level except for the 24.10-23.0 m interval, where there is a definite maximum. This maximum occurs in the same region where the wheels were found, but precedes the greatest of the three *Plumatella* maxima. If the black spheres are concretions of ferrous sulfide, as we suggest, then one might expect to find some relation between the numbers of black spheres and the time at which the hypolimnion first developed reducing conditions during summer stagnation, since the geochemistry of iron is strongly influenced by oxidation-reduction potentials. This is clearly not the case,

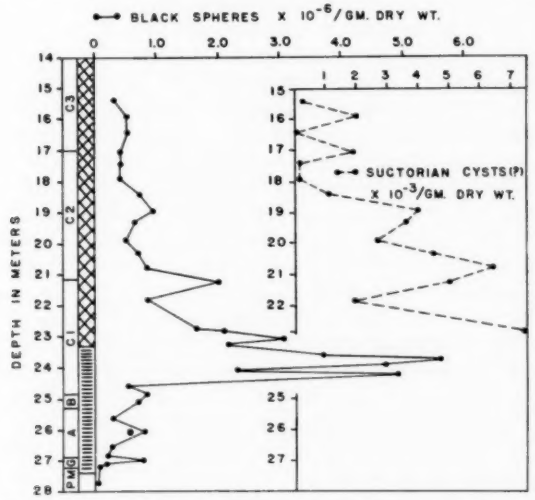

Fig. 7. Abundance of black spheres and suctorian cysts (?) per g dry weight plotted against depth. Suctorian cysts ( ) were present below the 23 m level but in greatly reduced numbers. Sediment zonations as in figure 1.

since they decline in numbers after the maximum. They may also have been secondarily deposited in deep water.

SUCTORIAN CYSTS (?)

Deevey (1942) identified structures in the sediments of Lower Linsley Pond which resembled cysts of the suctorian, *Podophrya fixa*. A single specimen from the LV profile was sent to Dr. R. R. Kudo for identification with the suggestion that the specimen might be a cyst of the above species. Dr. Kudo was unable to make a positive identification, and we therefore refer to this form as a suctorian cyst (?).

Below the 22.8 m level, suctorian cysts (?) were not noticed in the quantitative counts. They appeared first at 22.8 m in high numbers, and declined in an irregular manner thereafter, as shown in figure 7. Subsequent examination of levels below 23 m has shown that they are present but in much lower numbers. Here, evidently, is a form which shows some attributes of succession. It appeared first in high numbers at the level of maximum organic matter and remained in high numbers until the depth at the site of the LV profile decreased to 19 m. There is no definite evidence to show that succession is involved, and furthermore no evidence that these are in situ fossils.

PLANT FOSSILS

The profile was quantitatively analyzed for two plant constituents, the fragments of higher plants on the one hand, and sedimentary chlorophyll on the other. Data for both are given in arbitrary units. There is no way in which a quantitative comparison can be made between them except on a percentage basis. Data for sedimentary chlorophyll and higher plant fragments are shown graphically in figure 8, both per unit dry weight of sediment.

The gravel and sand zone was devoid of sedimentary chlorophyll. The silt-clay contained small amounts ranging from 0.1 to 0.6 sedimentary chlorophyll units per g dry weight of sediment. An abrupt rise in sedimentary chlorophyll was noted beginning with the zone of banded gyttja. Some of the increase was due simply to a decrease in the relative rate of inorganic sedimentation, but the peak does persist when results are given on a unit ignitable matter basis. This indicates an actual enrichment of sedimentary chlorophyll in the ignitable matter sedimented. Microscopic observation revealed a great increase in the numbers of diatoms (mostly *Cyclotella*) in the region of sedimentary chlorophyll increase at 27 m. The amount of higher plant fragments curiously showed a decrease during the same interval.

From 25.30 m to 22.50 m four peaks and three troughs in the sedimentary chlorophyll curve may be noted. The troughs were associated with low ignitable matter content of the sediment. The sedimentary chlorophyll per unit ignitable matter curve (not shown) has only the two upper peaks, indicating that the two lower peaks are to be accounted for by dilution of the sediment with inorganic materials.

It will be noted in figure 8 that the percentage increase in plant fragments during pollen zones A, B and C1 was much greater than that for sedimentary chlorophyll. Thus the ratio of the quantity of plant fragments at

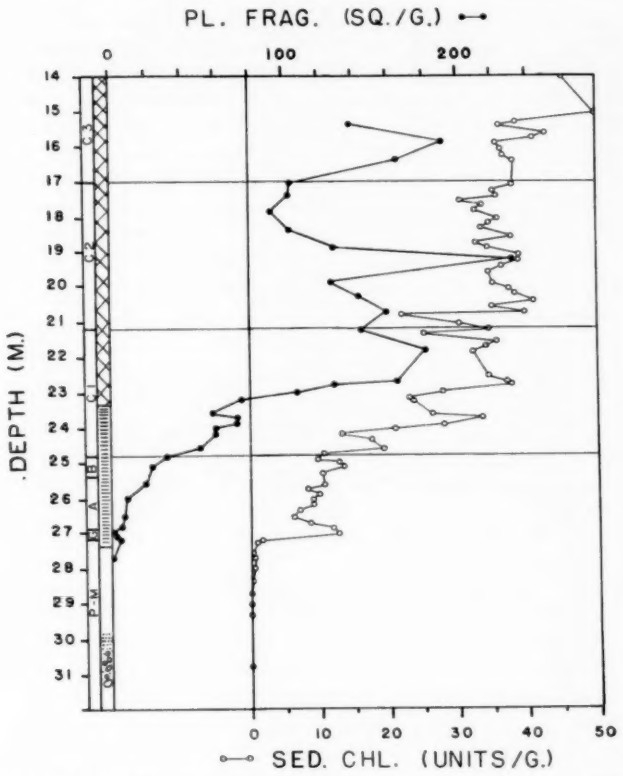

Fig. 8. Higher plant fragments (expressed as number of squares covered in an ocular micrometer) and sedimentary chlorophyll (expressed as sedimentary chlorophyll units) per g dry wt. plotted against depth. Sediment zonations as in figure 1.

22.7 m to that at 26.6 m was 21.1 as compared to 5.3 for sedimentary chlorophyll. Part of the increase in sedimentary chlorophyll in these pollen zones must have been due to the increase in higher plant fragments, but it is not possible to determine the extent of this influence from our arbitrary scale of values.

In upper C1, and all of C2 and C3, marked fluctuations in the abundance of higher plant fragments do not appear in the sedimentary chlorophyll curve. Nor is the reverse true. From these comparisons, on a percentage basis, it is concluded that the main source of sedimentary chlorophyll during this time was the phytoplankton and not parts of rooted vegetation. This may have also been true for earlier phases of the lake's history.

Microscopic examination of different parts of the profile was undertaken in order to compare the fluctuations in diatom populations with those of sedimentary chlorophyll. For both sedimentary chlorophyll and diatoms, the amounts or numbers were characterized as increasing, decreasing or remain-

ing constant over a given vertical range, resulting in nine different +, − or 0 combinations. Suffice it to say that each of the nine possible combinations was found at one or more levels in the profile. The reason for this is obvious: sedimentary chlorophyll is not derived solely from diatoms. We also feel that estimates of the abundance of plant life, based on sedimentary chlorophyll data alone, must be treated with great reserve and used in support of concepts only when supplemented by confirmatory evidence of an independent nature. The morphological and chemical structures of a plant will have their characteristic breakdown curves, and these are not likely to be identical for any one group of plants or for plants in general. Also the chlorophyll content of different plants and plant tissues varies greatly both with the species and the environment.

BOSMINA

In three of his profiles Deevey (1942) made quantitative counts of *Bosmina* heads and shells. This work has been repeated for the LV profile. We felt it advisable to count heads and shells separately, just in case the quantities differed. In the sediments of Linsley Pond the cladoceran heads and shells are almost always found separated. Of several thousand specimens examined in untreated mud, only three were found intact. The problem becomes one of adding two halves to see if the result is unity. Two counting methods were used:

Method 1. Each *Bosmina* head or fragment thereof was counted as unity. The shells of all Cladocera were counted. Each shell or fragment thereof was counted as unity. This method gives a Bh/Cs (*Bosmina* head/cladoceran shell) ratio. The ratios from such counts tend to be deceptively high because fragments of the head are more easily recognized than fragments of the shell. This method was used only on KOH-treated mud. The homogenization of the mud doubtless created some breakage.

Method 2. Each pair of *Bosmina* antennules was counted as unity, each single antennule as one-half. Each cladoceran shell was counted as unity if the two halves were together. Separate valves were counted as one-half. *Bosmina* shells were counted only if the mucro was present, antennules only if the small antennulary spine was present. This method gives a lower Bh/Cs ratio than Method 1.

Austin (1942) identified two species of *Bosmina* in the sediments of Linsley Pond. *Bosmina longispina* was found in sediments deposited before the middle of C1, and *B. longirostris* in sediments deposited after middle C1. Of all the specimens examined by Austin, only one shell of *Bosmina* contained a post-abdominal claw. In untreated mud from the LV profile 5-20 percent of the shells had post-abdominal claws. Austin used slides prepared by the KOH treatment. We have found that this treatment loosens the post-abdominal claws from their shells. Austin's identifications, however, are corroborated by our study of shell and post-abdominal claw form. The only statement made by Austin with which we do not agree is the lack of shells containing post-abdominal claws.

Deevey (1942) found a continuous increase in the number of *Bosmina* heads from the A1 pollen zone to the middle of the C1 pollen zone. He made

a significant contribution to paleolimnology when he showed that the increase in *Bosmina* was exponential relative to the increase in organic content of the sediment. His data conformed to the equation: $Y = bX^k$, where Y refers to the number of *Bosmina* heads, X to the organic matter content, and b and k are the empirical constants of the Y-intercept (when $X=1.0$) and slope when the logarithm of Y is plotted against the logarithm of X for a number of depths. The important point was that this equation, which has been so widely used in studying the development of organisms, can also be applied to the development of lakes. Figure 9 shows a graph of the numbers of *Bosmina* heads, cladoceran shells and the Bh/Cs ratios plotted against depth for the LV profile. The first

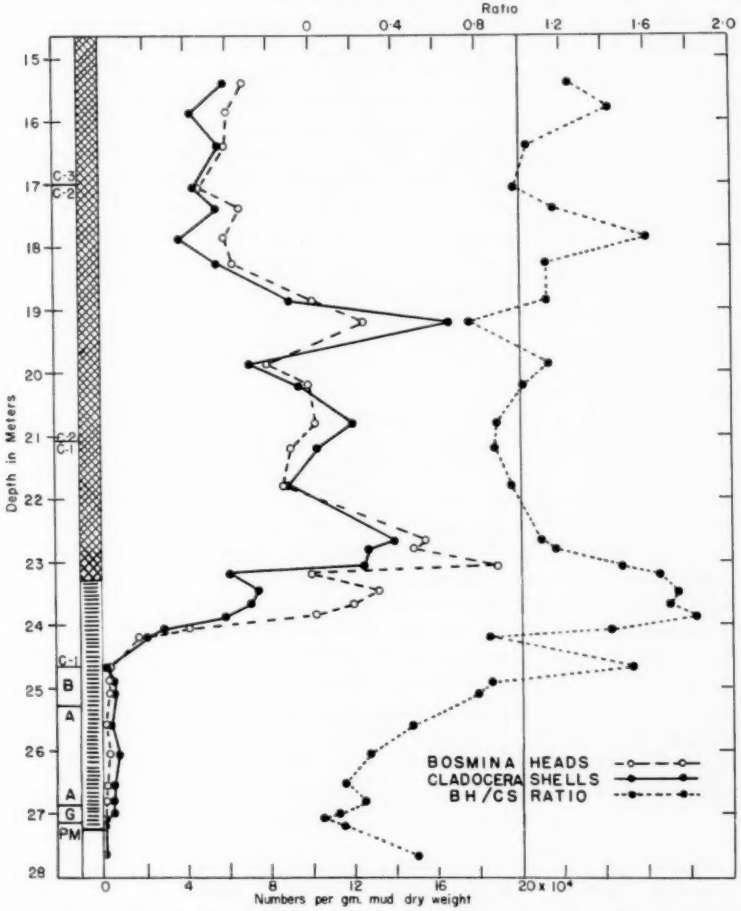

Fig. 9. *Bosmina* heads and cladoceran shells per g dry weight plotted against depth. The Bh/Cs ratios (*Bosmina* heads/cladoceran shells) plotted at the right. Sediment zonations as in figure 1.

marked increase in *Bosmina* heads occurred at the beginning of the C1 pollen zone, and the numbers reached a maximum in middle C1. When the log. of the number of *Bosmina* heads per g dry wt. is plotted against the log. of the ignitable matter content (% of dry weight) for levels in the zone of *Bosmina* increase, the data conform to a straight line. The equation of this line as determined by regression analysis is: $Y = 0.033\ X^{4.25}$. The corresponding equation for Deevey's data (half the sum of heads and shells per g dry wt.) from the L-10 profile is: $Y = 8.24\ X^{2.41}$. The lack of agreement between the two lines is shown in figure 10. Both the Y-intercepts and the slopes differ greatly. The biological meaning of the Y-intercept is simply the number of heads per g dry wt. when the percentage of ignitable matter is 1.0. This value is much higher for the L-10 profile than for the LV profile. Although some of the differences may be accounted for by different locations of the profiles, we feel that the major difference is due to the use of different sampling methods. Deevey (1942) used a Davis borer, which is more liable to contamination than the Livingstone sampler, but more important, his sampling intervals were much wider than ours. By appropriate selection of points on the LV *Bosmina* curve, one could approximate the regression line for the L-10 profile. For this reason we feel that the LV curve for *Bosmina* is better than the L-10. The rapid increase of *Bosmina* at a time when the abundance of oak pollen indicates warming of the climate is very suggestive.

The most conspicuous feature shown in figure 9 is the variation in the Bh/Cs ratio (*Bosmina* head/cladoceran shell) with depth. Three zones of the profile are distinct :

I. Below 24.0 m where the ratio is less than unity. Evidence is presented below to show that the percentage of non-*Bosmina* shells is high in this zone.

II. The zone of 24.0-22.7 m, where the Bh/Cs ratio is characteristically above unity, indicating a peculiar situation in which there are more heads than shells of *Bosmina*. Either the heads are better suited to preservation at this level or else there has been a sorting of the heads and shells after the deposition of the *Bosmina*, a sorting which enriched the LV site in heads. Evidence is presented below to favor both these interpretations.

III. Above 22.7 m where the Bh/Cs ratio fluctuates about unity. In this region nearly all the shells are those of *Bosmina*.

Subsequent examination of the LV profile indicated that the Bh/Cs curve shown in figure 9 is more regular than is actually the case. In region II (high Bh/Cs) one can find levels where the Bh/Cs ratio is near unity. There is also irregularity in the other two regions. The main division into three zones, however, is quite clear. In the next section, attention is focused on the conditions which prevailed in the lake at the time when the 24.0-22.7 m interval was deposited (*Bosmina* Zone II)

BREAKAGE IN BOSMINA ZONE II

In all the *Bosmina* analyses given below, fresh untreated mud was lightly mixed with distilled water and examined microscopically. Counting Method 2 was used unless otherwise noted.

Two representative samples were taken from each of the three *Bosmina* regions. Counts were made of the shells of *Bosmina*, those not *Bosmina*, and

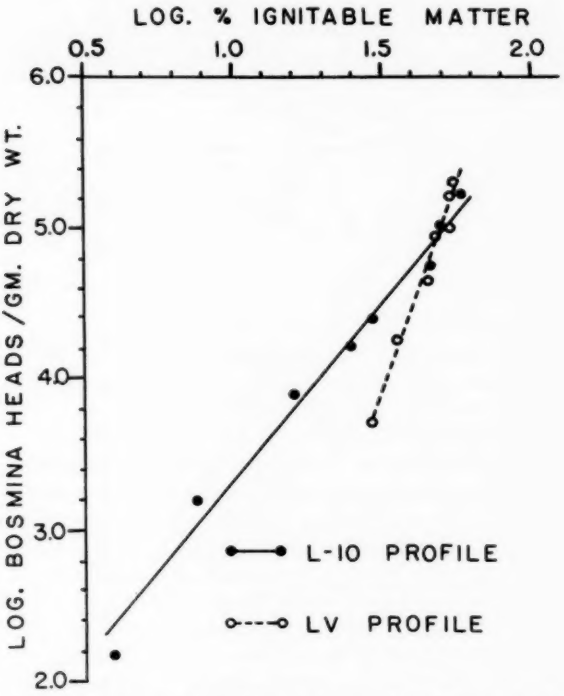

Fig. 10. Regression lines for the log. of the number of *Bosmina* heads per g dry weight plotted against the log. of the percent ignitable matter for a series of depths in the L-10 (data from Deevey) and the LV profiles.

those classed as inseparable because the critical parts for identification were either missing or obscured from view. Three hundred cladoceran shells were counted in each sample. A record was also kept of the number of heads of *Bosmina* seen in counting three hundred cladoceran shells. The data are recorded in table 2. The Bh/Bs (*Bosmina* head/*Bosmina* shell) ratio is seen to be approximately unity both in Zones I and III. The Bh/Bs ratio exceeds the Bh/Cs ratio in Zone II, as one would expect. If greater destruction of *Bosmina* shells is the reason for the high Bh/Bs ratios in Zone II, then it will be clear that this destruction occurred only in Zone II. The reason for the low Bh/Cs ratios in Zone I is simply the greater abundance of cladoceran shells other than *Bosmina*. The reason for the Bh/Cs ratios of approximately unity in Zone III is that nearly all the shells were *Bosmina*. Only Zone II requires detailed explanation.

The first clue as to the correct explanation came from a sample at the 23.53 m level. The Bh/Bs ratio (counting Method 2) for that sample was 1.42, as determined from 150 half-specimens. For the same sample the following ratios were determined: broken Bh/whole Bh (1.82); broken Bs/whole Bs (1.20); and whole Bh/whole Bs (1.07). A whole half-specimen refers to

TABLE 2

Percentage composition of shell counts in terms of *Bosmina*, non-*Bosmina* and inseparable shells, together with the Bh/Cs (*Bosmina* head/cladoceran shell) and Bh/Bs (*Bosmina* head/*Bosmina* shell) ratios for six depths. The 23.70 and 23.05 m samples lie in *Bosmina* Zone II.

Depth (m)	Shells			Bh/Cs	Bh/Bs
	Bosmina (%)	non-Bosmina (%)	Inseparable (%)		
16.30	92	3	5	1.02	1.04
19.70	86	6	8	1.00	1.06
23.05	89	3	8	1.54	1.59
23.70	88	7	5	1.58	1.71
26.20	58	32	10	0.56	0.92
26.90	66	25	9	0.57	0.87

one with all the exoskeleton intact, essentially as in the living animal. A broken half-specimen refers to any broken part, regardless of size. The point of significance is that the broken Bh/whole Bh ratio was 1.82 whereas the broken Bs/whole Bs ratio was only 1.20. The high Bh/Bs ratio is accounted for not by the unbroken heads but rather by a high proportion of broken heads. In order to show more clearly that this was the case, another counting method was used in which unbroken heads or their fragments were counted as unity if the two antennules were together (Bh-2) and as one-half for each separated antennule (Bh-1). *Bosmina* shells were counted as unity if the two valves were together, one-half for each separate valve, and no attention was paid to the degree of breakage of the shells. The results for a series of counts at different levels in the profile are shown in figure 11, where the Bh-1/Bh-2 ratio is plotted against the Bh/Bs ratio. The general trend is for a greater proportion of fragments with single antennules in samples with high Bh/Bs ratios. Although the scatter is great and the relation not exact in a statistical sense, there is little room to doubt that the high Bh/Bs ratios are characterized by an increased proportion of broken heads, i.e. those with single antennules.

There are two ways in which the increased proportion of broken heads of *Bosmina* might be accounted for. The first hypothesis is that both the heads and shells of *Bosmina* were subjected to breakage at the time when the sediments of Zone II were being deposited, such that the heads were less readily broken into unrecognizable fragments than were the shells. An experiment was performed to test this hypothesis. A sample of mud from 23.75 m was first found to have a Bh/Bs ratio of 1.05 and a Bh-1/Bh-2 ratio of 20.2. This sample was ground as a watery suspension in a mortar for 3 minutes, shaken vigorously in a test tube for 2 minutes, and stirred with an electrical stirrer for 30 minutes. After this treatment the Bh/Bs ratio had risen to 1.73 and the Bh-1/Bh-2 ratio to 43.0. These results suggest the correctness of the hypothesis listed above.

The second possible explanation for the region of high Bh/Bs ratios is that heads and shells were originally deposited in a 1:1 ratio throughout the lake, but currents later carried more of the half-specimen fragments into deep water than of the half-specimens themselves. Coupled with the greater ease in recognizing a broken head, this explanation could account for Zone

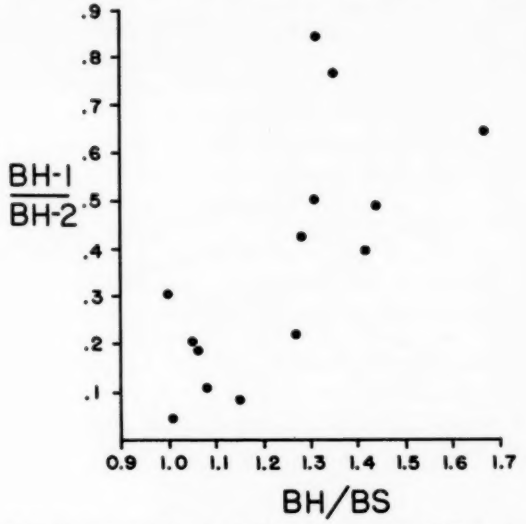

Fig. 11. Bh-1/Bh-2 ratio (*Bosmina* heads with 1 antennule/*Bosmina* heads with two antennules) plotted against the Bh/Bs ratio (*Bosmina* heads/*Bosmina* shells) for a series of depths. Data shown as a scatter diagram. High Bh-1/Bh-2 ratios indicate breakage of heads. Note the general increase in the Bh/Bs ratio with rising Bh-1/Bh-2 ratios.

II with the high Bh/Bs ratios. Brooks and Hutchinson (1950) have shown that small lake *Daphnia* obey Stokes' Law, i.e. have sinking rates proportional to the squares of their linear dimensions. The anterior and posterior carapaces of *Bosmina longirostris* (the species in Zone II) probably also fall within the range of Stokes' Law. A current passing over a deposit of *Bosmina* remains should tend to pick up the fragments and leave intact carapaces behind, thus effectively concentrating the fragments in deep water. As a test of this hypothesis, a mortar-ground sample was shaken and allowed to settle for 5 minutes in a tall test tube, 25 mm in diameter. At the end of that time the top 20 ml were removed. In the original sample the Bh-1/Bh-2 ratio was 0.56, and this had increased to 1.14 in the uppermost 20 ml after the sedimentation period. The test was repeated using the broken-whole method of counting. The result was that the uppermost 20 ml had a broken Bh/broken Bs ratio of 1.27 as compared to 0.89 in the original sample. It is clear that differential sinking rates for head and shell fragments as compared to intact heads and shells could account for Zone II.

Our interpretation of the data presented above is that the high Bh/Bs ratios from 24.0-22.7 m are a result of breakage. This zone appears to correspond in a general way to the First Major Disturbance Zone described by Patrick (1943), where extensive breakage of diatom tests was found and diatom populations were low. If the breakage explanation is correct then it should show up in other fossil structures. Counts of the percentage of broken *Pinus* pollen grains were made at several levels (100 grains counted for each sample) and also of the percentage of broken statoblasts (100 statoblasts

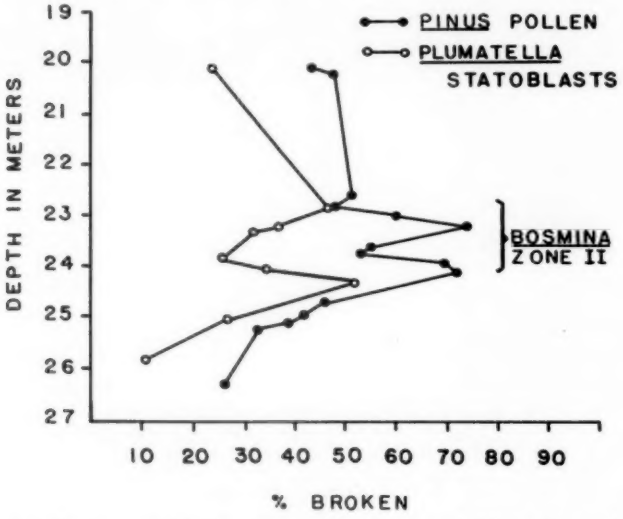

Fig. 12. Percentage of broken *Pinus* pollen grains and *Plumatella* statoblasts as a function of depth. The depth interval of *Bosmina* Zone II is shown on the right.

counted for each sample). A broken pine pollen grain was defined as one which either had developed a crack or else had part missing. A broken statoblast was defined as one in which the central area either was split or had part missing. The results of these counts are shown graphically in figure 12 and compared to the depth interval for the *Bosmina* Zone II. The curves show an increase in breakage reaching a maximum in *Bosmina* Zone II; however, the breakage does not decline very greatly above the upper limit of *Bosmina* Zone II. The pollen and statoblast data tend to support the breakage hypothesis, but other breakage criteria might have produced different curves. The strongest evidence for the breakage hypothesis lies in the high Bh/Bs ratios and the association of Zone II with the First Disturbance Zone described by Patrick. She suggested (1943) that *Bosmina* might have been a contributing cause to the diatom breakage in her Second Major Disturbance Zone, which occurred in middle C2. We have not studied the C2 Zone in as great detail as the C1 and do not know whether another *Bosmina* breakage zone was present there. If it was, then it must have been in between the samples which we analyzed. In any case, for Patrick's First Disturbance Zone our data suggest that both the diatom and *Bosmina* breakages resulted from the same phenomenon, and are therefore not connected as cause and effect.

It is difficult to imagine any factor other than turbulence which would induce breakage in diatoms, *Bosmina*, and possibly pine pollen and *Plumatella* statoblasts. If this notion is correct, our data argue for an increased turbulence in the breakage zone, or for an increased time over which turbulence acted. We have shown that both the breakage hypothesis and the secondary deposition hypothesis would account for the *Bosmina* results. Since turbulence and

breakage go hand in hand, our final interpretation is as follows. During middle C1 there was an increase in turbulence at the mud-water interface throughout the lake. This led to a grinding of mud constituents against each other, resulting in breakage of microfossils. As a result of the turbulence some of the fossils originally deposited in shallow water were carried to greater depths and redeposited. This accounts for both the breakage and the presence of epiphytes in deep water. During redeposition there was likely a certain amount of selective transport of fossils.

There is nothing in our data to suggest the mechanism by which turbulence might have been increased during middle C1. Deevey (1942) found a silt layer at a later time level in the sediments of Lyd Hyt Pond, Conn., which neighbors Linsley Pond. This silting phenomenon is of a different kind than the redeposition in Linsley Pond, since the silt was probably derived from outside the Pond. In Linsley Pond, the middle C1 sediments (at the LV site) are the most organic of any in the entire profile, and the hypothesis of secondary deposition during that time is tenable only if the redeposited sediment originated from the highly organic sediments within the lake. To have been carried in from another body of water is possible but unlikely because of the high organic content. Conceivably the breakage zone could have resulted from high winds introducing new current patterns, seiches or density currents and the like, but this is pure speculation.

CaO/MgO RATIOS

Hutchinson, Wollack and Setlow (1943) found that the CaO/MgO ratio in sediments of Tibetan lakes was much higher in closed lakes (no inlet, no outlet, no seepage) than in open lakes (with an inlet and an outlet). They suggested that water levels could be reconstructed for the history of a lake from a knowledge of the variations in the CaO/MgO ratio at different depth levels. At one time the senior author tenaciously supported the hypothesis of lowered water level as an explanation of the fossil epiphytes which Deevey (1942) found in the middle C1 sediments of his L-10 profile. The data for CaO/MgO given by Hutchinson and Wollack (1940) appeared to support this hypothesis: their data showed an increase in the CaO/MgO ratio from 1.5 and 1.8 in lower C1 to 4.5 and 4.0 in upper C1. If it could be shown that Linsley Pond were a closed lake in upper C1, and not a seepage lake (visible inlet, subsurface outlet), then the shift in the ratio could have a definite implication in terms of water level. It was clear from Deevey's work (1942) that silt-clay was at or near the base of each of his four profiles. If the silt-clay is impermeable to water, as pure clay often is, then the lake could have been closed if the water level had dropped. To summarize, we believe that Linsley Pond would have been a closed lake if it had lost its outlet, and on this assumption the variation in the CaO/MgO ratio in C1 sediments would prove or disprove the lowered water level hypothesis, providing that the theory of Hutchinson, Wollack and Setlow (1943) could be applied to Linsley Pond.

To obtain more extensive data than those given by Hutchinson and Wollack we had 31 samples analyzed spectrographically for CaO and MgO. Each sample was subjected to five separate burnings and the results averaged. The

TABLE 3

CaO, MgO and the CaO/MgO Ratio at 31 Levels of the LV Profile

Data for CaO and MgO expressed as a percentage of the ash.

Depth (m)	CaO	MgO	CaO/MgO	Depth (m)	CaO	MgO	CaO/MgO
15.75	2.50	1.00	2.50	24.55	2.45	1.29	1.90
17.10	2.33	1.05	2.22	24.70	3.15	0.82	3.84
17.30	2.42	1.20	2.02	24.90	3.39	0.92	3.68
17.75	2.79	1.14	2.45	25.10	2.46	0.85	2.89
20.35	2.93	1.27	2.31	25.80	2.34	1.04	2.25
22.55	2.94	1.27	2.31	26.30	2.45	1.19	2.06
22.70	4.11	3.72	1.10	26.52	10.80	0.72	15.00
22.80	3.79	1.56	2.43	26.60	1.60	1.02	1.57
22.95	3.95	1.55	2.55	26.70	2.70	1.05	2.57
23.20	2.46	1.19	2.07	26.80	7.20	1.39	5.18
23.60	3.25	1.33	2.44	26.90	17.20	1.25	13.76
23.75	1.62	0.44	3.68	27.00	8.90	1.37	6.50
23.95	2.28	0.62	3.68	27.10	1.49	1.45	1.03
24.20	3.03	1.07	2.83	27.20	1.60	2.10	0.76
24.30	3.25	1.08	3.01	27.30	1.59	1.90	0.84
				27.60	1.81	1.44	1.26

data are presented in table 3 together with the derived CaO/MgO ratios. There is evidence of slightly higher CaO/MgO ratios from 25.1 m to 23.75 m, the high values being caused mostly by the low percentages of MgO. This region underlies the zone where higher plant fragments and *Plumatella* statoblasts were most abundant, and gives no evidence that a lowered water level caused the abundance of epiphytes in the middle and upper section of the C1 pollen zone of the LV profile. The variations in the CaO/MgO ratio during C1 and other parts of the profile are probably not related to water level at all, but to the biological precipitation of $CaCO_3$. Hutchinson (personal communication) believes that the interpretation of CaO/MgO ratios is apt to be more complex in Connecticut sediments than was the case with the Tibetan sediments which he studied.

The high value for CaO and for the CaO/MgO ratio at 26.9 m was referred to above in connection with our suggestion that the 27 m level was deposited during the Two Creeks Interval. Another maximum for CaO and CaO/MgO was found at the 26.52 m level, a maximum which is peculiar to that level and which we are at a loss to explain. Neither of these early maxima were apparently due to mollusk shells, or conversely, if the maxima were due to the mollusk shells, they were fragmented to such an extent that we could not recognize them. The two early maximal CaO/MgO ratios probably do not relate to water levels. The cause may have been climatic as Deevey (1951) suggested for Maine lakes.

REINTERPRETATION

Before attempting to synthesize our data with those of previous workers let us consider the evidence for and against each of the three hypotheses invented to explain the occurrence of epiphytes in the middle C1 pollen zone of the LV and L-10 profiles.

Lower water level hypothesis.—Deevey (1942) presented three arguments against this hypothesis:

(1) There is no evidence of drying in shallow water profiles during the C1 zone.

(2) If a low water stage existed it would be more likely to have occurred during the xerothermic interval (C2) than during C1.

(3) If Linsley Pond were a closed lake in C1 then there should be high CaO/MgO ratios in sediments deposited at that time, and there are not.

To these three pieces of negative evidence, a fourth should be added: there is no evidence that the epiphytes were deposited at their place of growth. A fifth argument shows that Linsley Pond probably never had a greatly lowered water level. If it had, the removal of inflowing water would have to be accounted for either by a decreased precipitation/evaporation ratio or by seepage of water through the upper sediments. Seepage is unlikely because of the silt-clay seal around the bottom of the lake. On the other hand, the maximal rate of evaporation from Linsley Pond could hardly exceed that from Lake Mead during the summer, i.e. 500 g cal cm^{-2} day^{-1} (Anderson and Pritchard, 1951). If the Lake Mead rate is applied to Linsley Pond, and seepage negated, then it is necessary to conclude that precipitation was reduced to one-quarter of the present value during times of low water level. Such a conclusion disagrees with the vegetational history of Connecticut, which records C1 as a wet interval.

There are however three possibilities which should be investigated before this hypothesis can finally be disproved. First, it is possible that water level changes might have resulted from changes in the level of the surrounding water table, the latter fluctuating in sympathy with sea level (as Deevey suggested to us). Water levels are known to have fluctuated in bodies of water adjacent to the sea (Deevey, 1948); however, the changes in land elevation relative to sea level are poorly known for Connecticut. The second possibility is that the fossil wood in the C1 sediments of Upper Linsley Pond (Deevey and Potzger, 1951) was of the same age as the surrounding sediment, and not younger as was originally supposed. A final test of the lower water level hypothesis would be to compare the counts of C1 brown bands in shallow water profiles to those in deep water, providing that brown bands did form in the shallow water.

High transparency hypothesis.—Five arguments may be leveled against this hypothesis:

(1) The occurrence of gritty layers in the LV profile at a time when Deevey (1942) postulated high transparency appears to contradict the transparency hypothesis. To produce the gritty layers, turbulence and hence turbidity should have been high.

(2) The time of postulated high transparency overlaps the time at which Patrick (1943) showed that the diatom flora was richly eutrophic. At the time of high transparency the ratio of sedimentary chlorophyll to higher plant fragments indicates that most of the sedimentary chlorophyll was derived from the plankton, thus supporting Patrick's conclusion. In his transparency hypothesis, however, Deevey (1942) states:

"According to this hypothesis, these phenomena record a period of balance, when the increase in organic production had culminated through the increase in phytoplankton and littoral vegetation, but the phytoplankton had not yet begun to shade the lower water to such an extent as to reduce the total crop of rooted plants."

The concept of high numbers of phytoplankters and little shading is tenable, but rather unlikely.

(3) Except possibly for fragments of *Fontinalis* in A1 sediments, Deevey (1942) presented no evidence to show that the epiphytes lived at the locations in his profiles where they were found; this was not prerequisite to his transparency hypothesis, however.

(4) On this hypothesis one would expect the plant fragments to decline rapidly after middle C1, which they do not.

(5) High transparency fails to account for the extensive breakage in middle C1.

Deevey's hypothesis was that during middle C1 the transparency was greater than in the present-day lake, thus permitting rooted plants and their associated epiphytes to extend to greater depths. Deevey suggested that *Bosmina* remains were redeposited from shallow water into deep water and implied that this was the case for other microfossils, epiphytes included. Essentially he assumed that the rate of redeposition was constant. In order to explain the increased abundance of epiphytes in deep water during middle C1, he postulated that transparency was high, and that rooted plants grew below the level at which they grow today. This shortened the distance for transport to deep water and thus resulted in more transport of microfossils than would have been the case if the distance had been longer. We have found an increased breakage of microfossils in the C1 pollen zone, which suggests either a more turbulent transport or else a longer distance of transport. We do not feel that it is necessary to postulate a transparency much greater than in the present-day lake.

There are no primary data to favor the suggestion of high transparency during middle C1. Furthermore, to account for a peak in the number of epiphytes on the transparency hypothesis alone, one must suppose that the transparency was higher during middle C1 than immediately before or after.

Increased secondary deposition hypothesis.—Three arguments may be leveled against this hypothesis:

(1) The breakage of *Plumatella* statoblasts does not markedly decrease in sediments of the upper C1 and lower C2 pollen zones, as it should on this hypothesis.

(2) If the breakage of diatoms in the First Disturbance Zone of Patrick (1943) resulted from grinding action during turbulent redeposition, then one

might expect to find high numbers of fragmented diatom tests in deep water. Although Patrick did not count fragments, she did say that the number of diatoms was low in the First Disturbance Zone. Because of the small size of diatom fragments, one would expect slow sinking rates, but on the other hand the density difference between a diatom test and lake water is quite high (fast sinking rates). The increased abundance of epiphytic diatoms in middle and upper C1 sediments can be interpreted on the basis of increased secondary deposition, but it should be realized that a greater degree of turbulence would be required to transport these forms than would be the case for *Bosmina*.

(3) Objection (4) under the high transparency hypothesis also applies here.

The evidence favoring the hypothesis of increased secondary deposition rests primarily on the maximal breakage of pine pollen, *Bosmina*, and diatoms in middle C1. The increased breakage of statoblasts from lower to middle C1 may be used as confirmatory evidence but only with caution.

At the present time the evidence against the lower water level hypothesis is too great to consider it as a reasonable explanation. The hypothesis of high transparency is largely without positive supporting evidence and, since there are logical difficulties in the hypothesis (eutrophic plankton and little shading), it appears to be untenable. The hypothesis of increased secondary deposition is supported by the positive evidence of breakage. On the basis of present data, and the principle of Occam's razor, the secondary deposition hypothesis is accepted.

CONCLUDING REMARKS

It is gratifying to find similar trends in the numbers of microfossils at comparable levels in the LV and L-10 profiles. Although there are some marked differences between the two profiles, many, such as the occurrence of brown bands and the different statoblast maxima, were due to the use of different sampling procedures and the number of separate levels analyzed. The absurdity of reconstructing the history of a lake from a section just a little larger than a square inch in area is quickly appreciated, but in spite of the many assumptions involved, the approach appears to have some validity, even if only for deep water sediments.

The study of the history of Linsley Pond has just begun. Deevey (1955) no longer feels that climate has not influenced the development of American lakes, and our own work suggests that the initial rise in productivity and the increase in *Bosmina* in early C1 were both dependent on climate. The factors governing the sigmoid growth of the Linsley Pond biocoenosis (Hutchinson and Wollack, 1940) have yet to be elucidated. As D'Arcy W. Thompson (1942, p. 159) puts it: "The rise and fall of growth-rate, the acceleration followed by retardation which finds expression in the S-shaped curve, are seen alike in the growth of a population and of an individual, and in most things which have a beginning and an end." When the factors governing the S-shaped curve are understood, a new level of comprehension will have been reached, one which is surely basic to the whole study of limnology, both in its present and historical aspects. These and many other problems await

the student who wishes to capitalize on the knowledge of his predecessors, as we have done.

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OCCURRENCES OF LEUCOGRANOGABBRO AND ASSOCIATED IGNEOUS ROCKS IN THE WICHITA MOUNTAINS, OKLAHOMA

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ABSTRACT. A gabbro-granophyre complex of Precambrian age is exposed in the Wichita Mountains in southwestern Oklahoma. The complex probably forms horizontal sheet-like intrusions. Between the gabbro and granophyre a narrow zone of "intermediate rock" composed of leucogranogabbro, granogabbro, granodiorite, leucosyenogabbro, and syenogabbro exhibits peculiar mineralogical and textural characters. Field occurrences and petrographic studies indicate that these rocks originated as alteration products of the gabbroic rocks through contact action of a granophyric melt. As a result of the contact action, a uniform intermingling of gabbro and granophyre, together with partial granitization and hybridization, took place in the "intermediate zone." This paper presents a detailed account of the field occurrence, mineralogy, and petrography of the leucogranogabbro and associated igneous rocks.

INTRODUCTION

Although geological work has been done in the Wichita Mountains of southwestern Oklahoma by the State Geological Survey and by individual geologists, the spectacular development of the "intermediate rock" that occurs as a narrow zone between gabbro and granophyre of Precambrian age in the Wichita Mountains was not recognized there until recently (Huang, 1953). This narrow zone is composed of leucogranogabbro, granogabbro, granodiorite, leucosyenogabbro, and syenogabbro.[1]

Though Hoffman (1930, p. 32-35) studied the granogabbro of the Wichita Mountains and Johannsen adopted it as one of the representative types in his classification of igneous rocks (1939, p. 367-369), the occurrences of the leucogranogabbro and its related features were neglected by Hoffman and subsequent workers.

This paper presents a detailed account of the mineralogy, petrography, and related characters of the "intermediate rock." It is hoped that the present investigation may contribute to the petrology of the Wichita Mountains igneous complex, Oklahoma.

All optical measurements were made on a universal stage. In some sections of pyroxene and amphibole, extinction angles were determined according to Turner's method (1942); otherwise, the method of Burri (Haff, 1941) was frequently used. Refractive indices were determined by means of immersion methods, using sodium light.

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FIELD OCCURRENCE

The igneous rocks in the Wichita Mountains comprise a stratiform complex in which intrusions of granophyre cross-cut and overlie anorthosite and gabbro. The complex probably forms horizontal sheet-like intrusions. A

[1] For convenience, Johannsen's terms are adopted to denote the mineralogical composition of the "intermediate" rocks of the area under investigation.

narrow zone of "intermediate rock" composed of leucogranogabbro, granogabbro, granodiorite, leucosyenogabbro, and syenogabbro crops out along the general contact areas between the gabbro and granophyre. Many small patches of this "intermediate rock" occur in widely scattered localities in the area. A large outcrop of leucogranogabbro is at Twin Mountain; an outcrop composed of syenogabbro and granogabbro in Sec. 30, T. 4 N., R. 15 W.; leucogranogabbro and granogabbro in Sec. 8, T. 4 N., R. 14 W.; and leucosyenogabbro in Sec. 23, T. 3 N., R. 14 W. An excellent contact zone between gabbro and granophyre is found in Mount Sheridan. Here the contact zone ranges up to nearly 80 feet in width.

Most exposures of the leucogranogabbro and associated igneous rocks cover less than a quarter of a square mile and occur as low hills. Some are inliers surrounded by Permian red beds and recent deposits. The location of these rocks is indicated in figure 1. Many of the features described below are shown in a number of localities, but in order to present a comprehensive picture the descriptions are generalized.

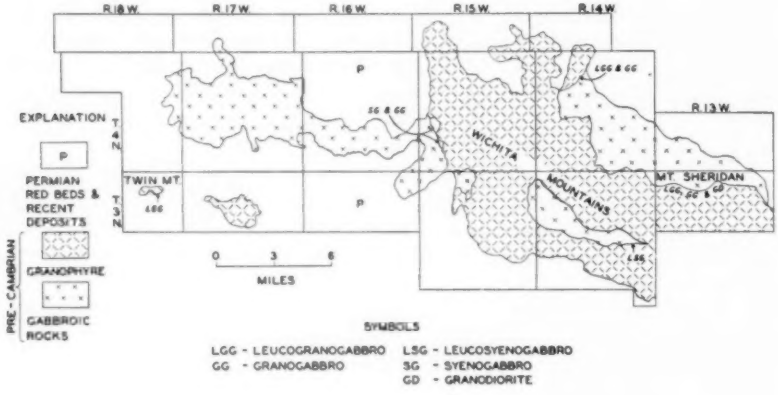


FIG. 1 SKETCH MAP SHOWING THE LOCATION OF LEUCOGRANOGABBRO AND ASSOCIATED IGNEOUS ROCKS, WICHITA MOUNTAINS, OKLA.

General nature of the contact effects.—The contact relations between gabbroic rocks and granophyre are complex and variable. Each feature is so involved with others that it can hardly be separated for description. In Mount Sheridan and elsewhere a well-defined contact is irregular on a small scale, but regular on a large scale (pl. 1-A). Although the phenomena are of great variety, they may all be regarded as the result of the attack and penetration of gabbroic rocks by a granophyric melt. They are closely allied, and their effects often merge, but the obvious results may be distinguished.

First is the attack and penetration of gabbroic rocks by a group of distinct but ramifying quartzo-feldspathic veinlets, ranging in width from 1-3 inches down to almost invisible seams. They bear a close resemblance in many respects to the reticulating stockworks of ore deposits, so that small masses of gabbro are intersected by many veinlets, at places nearly parallel,

elsewhere crossing and interlacing in all directions. The granitic materials have worked along cracks, joints, or blocks. Many other examples of this type of penetration may be described, and though they differ endlessly in detail, their major features are in most places much the same.

In a subsequent stage of penetration the main granitic dikes and veinlets finally break up into stringers in gabbroic rocks in the most intricate manner. Some granitic veinlets are nearly pure; elsewhere disintegration products of gabbroic rocks contaminate them greatly. At places the veinlets become dark, because bits of gabbro are scattered throughout them. Separate crystals of basic feldspar and pyroxene are associated with such magmatically incongruous minerals as quartz and alkalic feldspar. Finally a small mass of mixed rock, containing many ramifying veinlets and dikes, often intervenes between gabbro and granophyre. Commonly, a uniform, light gray matrix of modified gabbroic rock encloses large and small "islands" of less altered rock. This may be regarded as a second result of the intrusion of the granophyric melt.

A third result is the appearance of granitic material in the most minute interstices in masses of gabbroic rocks. At many places, swarms of riebeckite-bearing pegmatite veins and dikes up to 6.5 feet in width occur in the mixed rocks. The formation of these features together with the development of micrographic intergrowth and myrmekite to be described later is considered analogous to that of large-scale pegmatitization.

In banded anorthosite and gabbro, the granophyre sends small stringers and irregular protuberances along the bands. The great alteration of the banded rocks is attributed to their original structure, which is especially favorable for impregnation by granitic solutions. At many places the resulting products are uniform-looking altered rocks; at others, the irregular action has left nodules of nearly unaltered gabbroic rocks, of ghostly patches less contaminated than their surroundings; at still others the contamination has gone so far that rather large masses of rock have become more granitic than gabbroic. Rocks obviously intermediate in composition between gabbro and granite are assumed to represent a uniform intermingling of gabbro in granophyre, together with partial granitization and hybridization.

Textural features of the impregnated rocks.—The textures of these rocks are of two general types: (1) inhomogeneous and (2) uniform. In many exposures these types are closely associated, but the effects are fairly distinct. In the first, the gabbroic rocks are penetrated by pegmatite dikes, veinlets, and threads of granitic material. In the second, large masses of gabbroic rocks have been thoroughly modified in composition and have developed a uniform appearance resembling granite. This latter type of texture is by far the most abundant and dominant.

In appearance the mixed rock altered by veinlets is gray and reddish and of medium to fine, even grain, reminding one of the xenolithic "ghosts" found in masses of granitized rock. In some of the uniform mixed rocks a vague and almost imperceptible dappling or streakiness may be seen on close examination, but in many instances even this is absent. The original banded structure of anorthosite now converted to a mass of uniformly contaminated leuco-granogabbro at Twin Mountain may be preserved (pl. 1-B), but it naturally

PLATE 1

A

B

C—

A. Mount Sheridan from the northeast, showing the contact between the barren granophyre and the heavily wooded gabbroic rocks. Here the contact is irregular on a small scale but regular on a large scale; it is well defined.

B. Leucogranogabbro at Twin Mountain, showing the parallelism of feldspar tablets.

C. Leucogranogabbro at Twin Mountain, showing the unusually coarse feldspar crystals and pseudo-porphyritic texture. The original banded structure of anorthosite now converted to a mass of uniformly contaminated leucogranogabbro has lost its sharpness as the amounts of granitic materials introduced became abundant.

loses sharpness as the amounts of granitic material introduced became abundant (pl. 1-C).

Typically, the thoroughly mixed and impregnated rocks are dark gray to reddish rocks, medium grained, and occasionally pseudo-porphyritic and pseudo-diabasic. Very coarse varieties are also present but pass imperceptibly into rocks of normal grain size. The plagioclase laths occasionally reach the size of 18.5 cm in length and 2 cm in thickness (pl. 1-C), but the average size is 5 mm x 3 mm.

In Sec. 30, T. 4 N., R. 15 W., the syenogabbro and granogabbro have undergone uralitization. This process is especially intense along the joints and shattered areas of the outcrop. Amphibole needles are developed in the cracks and cleavages of clinopyroxene grains. Magnetite grains are scattered throughout. Alteration of feldspar is by no means as common or intense as that of the clinopyroxenes, but even in the freshest mixed rock an incipient alteration takes place at the center of the large feldspar crystals. Occasionally the alteration is intense, and the large feldspar crystal loses its pinkish color and becomes packed with small crystals which cannot be identified megascopically. The nature of uralitization on these mixed rocks is best studied under the microscope and it will be described later.

MINERALOGY

The chief minerals of the leucogranogabbro and associated igneous rocks are plagioclase, orthoclase, microperthite, quartz, clinopyroxenes, orthopyroxene, and amphiboles. Considerable amounts of tremolite-actinolite and pleochroic green or brown hornblende, magnetite, epidote, and chlorite accompany the altered clinopyroxenes. Table 3 shows the selected modal analyses of the rocks.

Feldspar.—Plagioclase, generally lath-like, normally constitutes over half the volume of the rock. Except for a few very large crystals, the grain size averages 4 mm x 5 mm and is comparable to the associated mafic minerals. The total range in composition is from An_{58} to An_{70}, but the great majority is near An_{68}. Thus, the plagioclase is labradorite.

Twinning is widely developed, and twinning laws were determined by the migration curves (Turner, 1947). Albite twinning is the most abundant; but Carlsbad, Ala, Pericline and complex twinning are also present. Some plagioclase crystals occur as slender zoned laths, but most are unzoned, or occasionally occur as poikilitic crystals of more uniform composition. The laths were formed by crystallization in a magma undergoing movement, whereas the unzoned and poikilitic habits are ascribed to crystallization in a quiescent magma. The zoned crystals have compositions ranging from An_{70} to An_{50}, and the average ranges from An_{68} to An_{58}. Sharply defined zones present; but the transition in composition from the core to the edge is commonly gradual.

Andesine with An_{32-36} occurs as laths exhibiting twinning. It is confined to granodiorite, where contamination of gabbroic rocks by granophyric melt has produced a rock more granitic than gabbroic.

A little albite occurs in the granogabbro and syenogabbro. Vermicular and scalloped masses of albite anastomose through the borders and cores of

orthoclase and plagioclase in a very complex manner. In myrmekite the albite is cloudy, contains sericite inclusions, and forms rosettes radiating from a central crystal, which commonly has both polysynthetic and Carlsbad twinning. The central crystal and the radiating rosettes include blebs and hook-like masses of quartz all of which show uniform optical orientation over small segments of a single rosette, though in cases two or three such quartz crystals are required to compose the entire rosette. The albite of these rocks has extinction angles as large as 15° in the zone normal to 010, and indices of refraction are all lower than 1.537. The feldspar is therefore at least as sodic as $Ab_{95}An_5$.

Most of the more sodic feldspars, albite-oligoclase with An_{9-22}, are perthitic. Two types of microperthite were noted: vein microperthite and patch microperthite; the latter predominates. The vein microperthite consists of albite-oligoclase in narrow, even-spaced lamellae in orthoclase, whereas the patch type is composed of albite-oligoclase irregularly intergrown with orthoclase. Part of the albite-oligoclase replaced the host as islands of orthoclase were found in the albite-oligoclase. Microperthite crystals vary in size considerably and average 1.5 mm x 1.8 mm in dimensions.

Orthoclase free from perthitic intergrowth occurs in small amounts. Most crystals are untwinned, but are turbid owing to inclusions of sericite. The orthoclase crystals vary in size from small to large, 1.2 mm x 2.6 mm, and average 0.3 mm x 0.8 mm. Traces of microcline are confined to granodiorite and granogabbro.

Clinopyroxene.—A small amount of clinopyroxene occurs in leucogranogabbro, but it increases in amount in granogabbro. Clinopyroxene forms subhedral crystals averaging 1.4 mm and up to 2.8 mm in diameter. It is usually colorless in thin section, but occasionally it is pale green with no pleochroism. The presence of partings on both (100) and (001) makes the variety name diallage appropriate.

The extinction angle and 2V were measured in every thin section; β index was determined when the mineral was available. The chemical composition of the mineral based on Hess' method (1949) are shown as follows:

TABLE 1

Optical Data on Clinopyroxenes

Specimen	2V	Z∧c	β index	inferred composition
H-25	44°-49°	42°-46°	1.682 ± 0.003	$Wo_{42}En_{48}Fs_{10}$
H-31	52°-54°	45°	1.688 ± 0.002	$Wo_{41}En_{43}Fs_{16}$
H-42	52°-53°	45°-48°	1.692 ± 0.002	$Wo_{38}En_{41}Fs_{20}$

Inclusions are seldom present. Possible exsolution of orthopyroxene may exist but could not be positively demonstrated. Uralitization of clinopyroxene along cleavages and cracks produced secondary hornblende, which in turn changes to chlorite (pl. 2-A).

Orthopyroxene.—The mineral occurs as oblong-shaped crystals which average about 0.2 mm by 1.3 mm in dimensions. The orthopyroxene was

determined with Hess and Phillips' curve (1940). Optical properties of orthopyroxene are: (−) 2V = 63°, N = 1.702 ± 0.003, faintly pleochroic: X = pinkish, Y = colorless, and Z = pale to greenish. These data indicate hypersthene with an enstatite content of $En_{73}Of_{27}$.

Some hypersthenes contain schiller inclusions, which are composed of fine needles arranged parallel to the c-axis. The hypersthene is commonly fresh, but not infrequently shows alteration to tremolitic amphibole and green serpentine-like mineral.

Amphibole.—This mineral occurs in considerable amounts in granodiorite and some uralitized syenogabbro and granogabbro. The optical angle, Z∧c, and the β index were determined. Exact compositions from optical data are impossible to obtain, but approximate compositions, according to Sundius (1946), are shown in table 2.

TABLE 2

Optical Data on Amphiboles

Specimen	Pleochroism		2V	Z∧c	β index	Mg	Related	
						Mg+Fe	En	An
Tremolite-actinolite								
H-25	colorless		−85°	17°-20°	1.618±0.003	90%		58
H-48	greenish		−78°-85°	14°-20°	1.635±0.003	75%	73	70
Hornblende-pargasite								
	X	Y=Z						
H-31	yellow	green	−80°-82°	13°-16°	1.636±0.003	80%	73	62
H-46	bluish	green	−64°-88°	12°-15°	1.670±0.003	50%		36
H-52	brown	yellow	+84°	13°-15°	1.662±0.002	60%		36
H-56	green	grass-green	−76°	13°-16°	1.654±0.001	65%		68

Amphiboles vary in appearance. The primary amphibole is subhedral to euhedral and is quite fresh. The secondary amphibole which was formed by uralitization is poikilitic, and anhedral (pl. 2-B). Grain size of primary hornblende is of the magnitude of 1.2 mm x 0.3 mm; others vary with the stage of uralitization and the original size of clinopyroxene, up to 1.5 mm in length. Pleochroism is distinct: X = yellowish green, Y = Z = green to blue-green; (−)2V = 80, Z∧c = 16°. Some hornblende is brown and is rich in minute iron inclusions. The mineral occurs in irregular patches without any crystal form and is invariably associated with clinopyroxene which has undergone uralitization.

Other accessory minerals are quartz, apatite, sillimanite, biotite, sphene, and zircon; secondary minerals include ilmenite, magnetite, serpentine, epidote, sericite, uralite. Quartz occurs in considerable amount in rocks near the granophyre while apatite is particularly abundant in rocks adjacent to the pegmatite contact. Except for epidote and serpentine, most of these minerals are euhedral to subhedral.

TABLE 3

Selected Modal Analyses of the Leucogranogabbro and Associated Igneous Rocks in the Wichita Mountains, Oklahoma

	1 Leuco-granogabbro	2 Grano-gabbro	3 Uralitized granogabbro	4 Grano-diorite	5 Leuco-syenogabbro	6 Syeno-gabbro
Quartz	8.7	8.0	8.8	13.8	tr.	tr.
Orthoclase	2.2	3.4*	1.2	5.8*	8.4	5.2
Microperthite	15.4	15.2	13.5	5.2	tr.	tr.
Labradorite	70.7	54.0	30.0	tr.	90.0	68.0
Andesine				36.0		
Clinopyroxene	1.0	7.5	3.5	2.5		4.8
Orthopyroxene		5.2	4.5			5.2
Amphibole	0.5	2.2	14.5	27.0	1.4	4.2
Sillimanite		tr.	tr.			
Biotite	tr.	0.5	1.4	1.5		2.6
Zircon	tr.		tr.	tr.		tr.
Sphene	tr.	tr.	tr.	2.1		2.4
Apatite	1.5	2.0	4.6	4.5	tr.	2.5
Magnetite	tr.	0.5	6.2	1.5	tr.	2.6
Ilmenite			tr.	tr.		
Chlorite		tr.	6.5**	0.1	0.2	tr.
Epidote	tr.	1.5	2.3	tr.		2.5
Sericite	tr.	tr.	0.5		tr.	
Uralite			1.5			tr.
Serpentine		tr.	1.0			tr.

tr.—trace.

*Trace amount of microcline is included, and small amounts of albite were found in granogabbro and syenogabbro.

**Considerable amount of penninite is included.

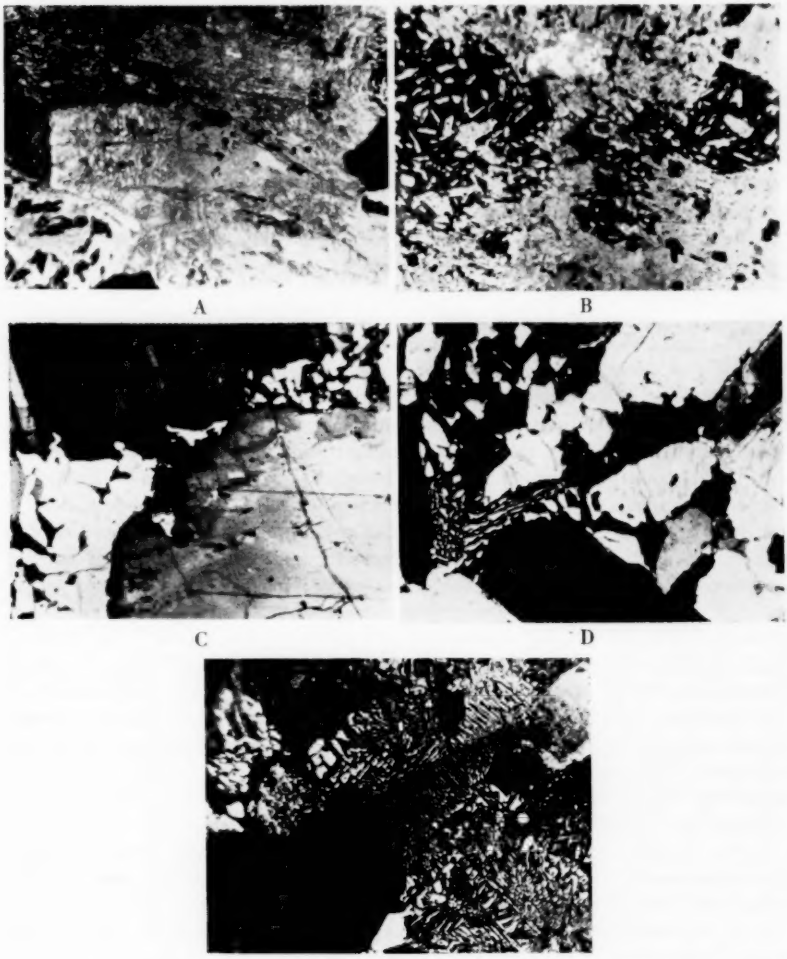
1. Leucogranogabbro, Twin Mountain.
2. Granogabbro, NE corner Sec. 8, T. 4 N., R. 14 W.
3. Uralitized granogabbro, Sec. 30, T. 4 N., R 15 W.
4. Granodiorite, Mount Sheridan.
5. Leucosyenogabbro, Sec. 23, T. 3 N., R 14 W.
6. Syenogabbro, Sec. 30, T. 4 N., R. 15 W.

PETROGRAPHY

In describing the petrography of the rocks, the following features are worthy of attention:

(1) Different habits of the quartz crystals indicate that the history of crystallization of quartz was complex. Some quartz, with euhedral shape, occurs in the orthoclase as inclusions; large subhedral quartz grains are present, but the majority occur as anhedral grains and are generally interstitial. Others have penetrated and replaced plagioclase and orthoclase in myrmekitic-like blebs or have formed "brain-coral" myrmekite (pl. 2-C) and and graphic intergrowth (pl. 2-D and E). These graphically intergrown quartz and myrmekitic quartz are believed to be the latest formation of quartz. Thus, four stages of quartz deposition, each with its own particular habit, are indicated.

PLATE 2



A. Uralitized clinopyroxene crystals in granogabbro, Sec. 30, T. 4 N., R. 15 W., Wichita Mountains.

X 24, ordinary light.

B. Poikilitic hornblende in uralitized granogabbro, Sec. 30, T. 4 N., R. 15 W., Wichita Mountains.

X 24, ordinary light.

C. "Brain-coral" myrmekite in leucogranogabbro, Twin Mountain.

X 80, nicols crossed.

D. Gradual development of micrographic intergrowth of quartz and feldspar. Note that the quartz grains are in fine-grained and finger-like patterns. Leucogranogabbro, Twin Mountain.

X 34, nicols crossed.

E. Spectacular development of micrographic texture in leucogranogabbro. Twin Mountain. The feldspar grains form the host within which quartz ramifies in a fingering pattern or appears as parallel streaks. Note that one feldspar grain still retains Carlsbad twinning.

X 34, nicols crossed.

(2) The gradual development of graphic intergrowths of quartz and plagioclase by replacement of feldspar is noteworthy. All stages are present from corroded crystals to small scattered relics in optical continuity. Residual pools of feldspar often have wispy sericite developing on or near the replacement front, probably representing a part of the liberated K_2O and Al_2O_3. In the more advanced stages, graphic intergrowth is then evolved by the development of fine-grained, diamond-shaped, fingering-like patterns. Either the orthoclase or the plagioclase may form the host within which quartz ramifies in a fingering pattern or appears as parallel streaks. Considerable areas of quartz are optically continuous. Many large crystals of plagioclase still retain their oscillatory zoning and Carlsbad twinning (pl. 2-E). From this description it is recognized that graphic texture in this particular instance is not necessarily a result of crystallization of a magma of eutectic composition.

(3) A characteristic feature of the leucogranogabbro and associated igneous rocks adjacent to granophyre and pegmatite contacts is the development of myrmekitic intergrowth of plagioclase and highly vermicular quartz. Many myrmekites develop where crystals of plagioclase are in direct contact with orthoclase or microperthite, and are thus generally held to be a product of replacement of potash feldspar by plagioclase. A similar description is given by Tilley (1921, p. 87-88) and Read (1931, p. 149). According to Tilley (p. 88), the formation of myrmekite in granitic rocks is a special phase of albitization.

As already noted, the impregnated rocks in the Wichita Mountains are cut by riebeckite-bearing pegmatites. The albite solution essential to replacement may be derived not only from residual magma extracts but also from the pegmatitic fluids reacting upon the invaded rocks. The development of myrmekite in all the sections examined is significant. Where the myrmekite occurs on the borders of orthoclase, it indicates the presence of albitizing solutions. The development of the incipient and other forms of albite is probably also caused by the presence of such solutions, and occurs in the same phase of alteration as the myrmekite. These changes were accompanied by considerable sericitization of the feldspars and the chloritization of biotite and hornblende. Some epidote is clearly secondary and has replaced the plagioclase and other constituents.

It is evident that the igneous rocks as a whole have been subjected to some hydrothermal changes since consolidation. These changes include an addition of soda to form myrmekite and incipient albite, the addition of silica to form quartz, and the addition of lime to form epidote. It is suggested that these hydrothermal changes in the igneous rocks were produced by the residual magma extracts, which acted upon the consolidated portions of the rock. In other words, the changes were deuteric, or epi-magmatic.

Gilluly, from the field and microscopic evidence, has discussed and described similar changes in a diorite related to the origin of albite granite near Sparta, Oregon (1933, p. 71-81). He considers it probable that the formation of the myrmekite in albite granite indicates the existence of post-magmatic albitic solutions. He reviews the literature on the subject giving many references on its formation. He considers the presence of lobate quartz as

evidence of silicification, and also the widespread occurrence of epidote, rather than other mafic minerals, as suggesting hydrothermal processes (p.74).

(4) The association of brown and green hornblende calls for comment. Walker (1940) described brown and green uralite hornblendes in Palisade diabase. Shand (1942) found that brown and green hornblendes occurred in both the diorites and norites of Cortlandt, New York, and suspected the only reason for the color to be the degree of alteration. The useful criterion for the separation of hornblende was crystal habit, prismatic indicating an early crystallization, and poikilitic, a later deuteric one. Kunitz (1930) thought titania is the probable cause of brown pleochroism in basaltic hornblendes.

Brown poikilitic hornblende, then, is not necessarily primary because of its color, which may be due to alteration or presence of titania, but rather the result of later deuteric action, which is also responsible for the poikilitic green hornblende. Optical properties cannot be used to differentiate poikilitic from prismatic and brown from green. The only valid criterion is external crystalline form. In the light of this discussion, the writer found Shand's (1942, p. 416) observation of color due to degree of alteration is the easiest to accept.

(5) As already noted, the syenogabbro and granogabbro in Sec. 30, T. 4 N., R. 15 W, have undergone uralitization. In the first stage of this alteration, clinopyroxenes have become decomposed, then amphibole needles have developed around the edges, cracks and cleavages of clinopyroxene grains. As uralitization proceeds, the mafic minerals are completely replaced by fibrous aggregate of amphiboles. Magnetite is thrown out in the process and forms small grains along cleavages, or is scattered in the relics of clinopyroxene grains. The original structures and inclusions are preserved, and the amphibole pseudomorph looks exactly like clinopyroxene in ordinary light. Diallage appears to change directly to pale green uralitic amphibole, which commonly reacts with plagioclase to form a deeper green border. Hypersthene changed first to fibrous aggregates of colorless tremolitic amphibole, which reacted with adjacent plagioclase to form green borders, and subsequently changed completely to green uralite and serpentine.

In the advanced stage of uralitization, all clinopyroxene structures disappeared, and the uralite recrystallized to a deeper green and more pleochroic hornblende. Magnetite and ilmenite collected into clots associated with amphiboles. Remnants of clinopyroxene were retained.

In the final stage of uralitization, small amphibole needles developed in the feldspars. Hornblende was replaced by aggregates of anomalous blue penninite, and epidote makes its appearance.

The uralitized rocks have been derived from the gabbroic rocks, after their consolidation, by the action of residual liquids and vapors from the invading granophyric melt. Intrusion of granite accompanied by pegmatite and aplitic dikes could conceivably have caused such uralitization by pneumatolytic action, as the uralitized rocks are commonly cut by dikes, and usually occur along joints and shattered areas of the outcrop. Small amounts of silica must have been introduced during the process of uralitization, as some feldspar grains had been replaced by late quartz; a similar conclusion has been given

by Oliver in his studies of uralitization on Sudbury norite (1951, p. 427-429).

Read (1935, p. 606) described the chemical analysis of the uralitized quartz-gabbro as having higher percentage of H_2O than the normal quartz-gabbro. It appears that the introduction of water could have produced such a change just described.

In view of the intense hydrothermal activity in the Wichita Mountains, it is believed, then, that the uralitization of the syenogabbro and granogabbro is due to the permeation of liquids and vapors of the invading granophyric melt through the gabbroic rocks.

ORIGIN OF LEUCOGRANOGABBRO AND ASSOCIATED IGNEOUS ROCKS

Field occurrences and petrographic studies show that the leucogranogabbro and associated igneous rocks are not differentiated in their present forms from one magma, but represent altered products of the gabbroic rocks through contact action of a granophyric melt. These rocks obviously intermediate in composition between granite and gabbro are assumed to represent a uniform intermingling of gabbro and granophyre, together with partial granitization and hybridization. The following features are highly significant and support the view just set forth.

Field relationships.—The leucogranogabbro and associated igneous rocks contaminated with granitic materials and veined with pegmatites, as described, occur as "intermediate rock" along the contacts between gabbroic rocks and granophyre throughout the Wichita Mountains, Oklahoma. At Twin Mountain and elsewhere masses of anorthosite are converted to mixed rocks by granophyric impregnation. Riebeckite-bearing pegmatites occur in the rocks near the contact. Away from the contact, veins and nests of pegmatite are absent, but separate crystals of basic feldspar in anorthosite are associated with such magmatically incongruous minerals as quartz, orthoclase and microperthite. Commonly, a uniform, light gray to reddish-gray matrix of modified anorthosite encloses large and small "islands" of less altered rock. In many places, however, the anorthosite mass is thoroughly impregnated and mixed with granophyric materials, leading to the development of leucogranogabbro and leucosyenogabbro.

In Mount Sheridan and elsewhere the gabbroic rocks are altered by a group of distinct but ramifying quartzo-feldspathic veinlets resembling the reticulating stockworks of ore deposits. Many quartzo-feldspathic veinlets are pure; elsewhere disintegration products of gabbroic rocks contaminate them greatly. The occurrence of these veinlets in the gabbro illustrates the contact action of a granophyric melt when in non-equilibrium with the rock. Pseudodiabasic texture of the "intermediate rock" may develop near the gabbro, but it becomes less prominent away from it. Granophyric materials are found in the minute interstices in masses of gabbroic rocks. The rocks are converted to granogabbro and syenogabbro. At places the contact action has gone so far that a mass of rock has become more granitic than gabbroic, developing granodiorite.

Thus, the field relationships alone unequivocally indicate that transformation of anorthosite into leucocratic mixed rocks and gabbro to melanocratic

mixed rocks was a result of contact action of the intruded granophyric melt on the solidified gabbro. Perhaps both mechanical and chemical processes were responsible for the peculiar mineralogical and textural features of the "intermediate rock." Mechanical processes are indicated by fracture fillings and sporadic occurrence of lit-par-lit injections.

The dominant genetic process appears to be introdution of granophyric materials through chemical processes, i.e., diffusion. Intermixture of two different materials and partial granitization occurred under conditions of contact alteration. Here, gabbro and granophyre differ greatly in composition, and it is concluded that these differences were in large part responsible for the chemical processes (Ramberg, 1945, p. 106). In addition, a temperature gradient between the hot granophyre and solidified gabbro probably existed. These two factors, temperature and composition, are regarded as the greatest factors in the chemical activity gradients.

The importance of large-scale impregnation and soaking of the surrounding rocks during granitic invasions is well known. In the present area, the magmatic impregnation responsible for the formation of the leucogranogabbro and associated igneous rocks was related also to the pegmatitic phase of igneous intrusion as evidenced by the field occurrence of the rocks.

Presence of micrographic intergrowth and myrmekite.—The development of micrographic texture and myrmekite in the leucogranogabbro and associated igneous rocks has already been described. Numerous descriptions of more or less similar micrographic intergrowths of all kinds are found in the literature, and appear to be highly characteristic of rocks formed near igneous contacts as a result of incomplete reaction between magmatic fluids and invaded rocks. Such intergrowths also indicate a potency of granitization processes. In view of the above facts, it is concluded that the intergrowths described in the mixed rocks originated during the later stages of the pegmatitic phase of reaction. Quartz partially replaced original plagioclase, orthoclase, microperthite or biotite, large crystals of which now act as hosts to the graphic or vermicular quartz inclusions.

Quartz fabrics.—The banded structure of anorthosite now converted to leucogranogabbro and leucosyenogabbro is locally preserved, and parallelism of plagioclase tablets is well developed in some areas of the rock. This parallelism of feldspar is discernible megascopically only in the most favorable cases, but under the microscope is often seen even in random sections. It follows, therefore, that there is a strong indication that its occurrence is not a matter of chance but that it is related in origin to magmatic flow (Walper, 1951, p. 51) at the time the basic magma was emplaced.

Fabric diagrams were made showing the distribution of 180 quartz axes in leucogranogabbro. Three thin sections were cut from a selected specimen parallel to three planes at right angles to one another. The vertical line of figure 2-A indicates the section parallel to the trends of bands. Three fabric diagrams, all from one specimen, are shown in figure 2. These diagrams appear to have a completely haphazard arrangement of fabric elements.

In the writer's previous studies, the olivine in flow-banded troctolites shows marked preferred orientation with Y and Z in the plane of banding

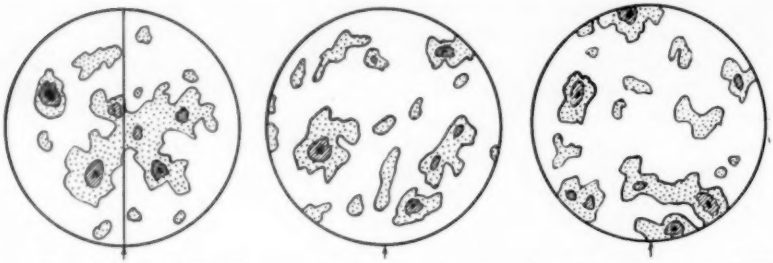


Fig. 2. Petrofabric diagrams showing the plot on each of the optic axes of 180 quartz crystals. Contour intervals: 1-2%, 2-4%, and over 4%. Diagrams are from three mutually perpendicular thin sections, cut from one specimen of leucogranogabbro at Twin Mountain. The vertical line of figure A indicates the section parallel to the trends of bands.

(Huang and Merritt, 1952), and the feldspar grains in banded anorthosite have their faces (010) preferably parallel to the plane of banding (Huang 1954). Petrofabric studies of quartz indicate that it is susceptible to reorientation when subjected to deforming influence and movement (Turner, 1948, p. 192, 211). Hence the completely haphazard quartz diagrams of the leucogranogabbro from Twin Mountain appear to indicate that the positions of the quartz crystals are unrelated to the force which has produced the preferred orientation of olivine and plagioclase parallelism.

From the foregoing analyses of the haphazard orientations of quartz and from the fact that most quartz grains are characteristically interstitial fillings, it is clear that the intrusion of the granophyric materials and the attendant injection of pegmatitic fluids into the already solidified anorthosite was a result of late magmatic impregnation along and across the bandings. These bandings are avenues of weakness, along which the fluid felsic materials are most capable of intimate penetration.

Mineralogical features.—Leighton stated (1954, p. 433) that chemical investigation failed to distinguish between a primary or secondary origin for the "intermediate rock." The writer thus has emphasized the field and petrographic nature of the rocks for the interpretation of origin. The following mineralogical features are highly significant.

The sillimanite of the granogabbro is strictly confined to the area immediately adjacent to pegmatite contacts, and it may be reasonably inferred that one of the conditions essential for its development was through permeation of pegmatitic fluids. Though the writer (Huang and Merritt, 1954, p. 563) interprets the presence of sillimanite in anorthosite and considerable amounts of spinel in the associated troctolites of the Wichita Mountains as products of the assimilation of argillaceous sediment, the occurrence of sillimanite clearly derived from pegmatite in the granogabbro does not seem to indicate conclusively that the production of this mineral was due to assimilation of argillaceous sediment. The fact that andalusite and sillimanite in granitic rocks are not always contamination products has been critically discussed by Hills (1938). From the field and petrographic evidence, the presence of silli-

manite in granogabbro indicates conclusively that the pegmatites were injected into the invaded rocks, and that the sillimanite is derived from the pegmatitic phase of igneous intrusion.

The abundance of apatite in the "intermediate zone" indicates alteration. Nockolds (1933) believed that concentration of apatite in basic rocks intruded, or included, by acidic magmas is a result of volatile action.

Sphene, while not found in gabbroic rocks and granophyre of this area, does occur in the leucogranogabbro and associated igneous rocks. That the sphene crystals are commonly associated with quartzo-feldspathic materials is no doubt to emanations from the adjacent masses of granophyre and pegmatite.

The abundance of hornblende in granodiorite, as compared to the paucity of that mineral in granophyre of the area, clearly indicates that it has been formed in the presence of hydrous fluids at the end stage of granitic action.

The blotchy appearance of amphibole crystals with their variability of pleochroism and other optical properties in uralitized mixed rocks is hardly suggestive of primary origin. The blue-green patches on many amphibole crystals suggest introduction of soda. Also, the occurrence in felty aggregates and irregular crystals suggests alteration processes after pyroxenes. Clots of magnetite and ilmenite were thrown out in the processes.

Ghostlike remnants of plagioclase in the intermediate zone show considerable epidote and sericite. The lime in the epidote suggests that the plagioclase was formerly more calcic.

The peculiar albitic stringers cutting through more basic plagioclases illustrate the action of sodic solution, a phenomenon similar to that of metasomatic albite granite near Sparta, Oregon (Gilluly, 1933, p. 68).

Introduction of silica is abundantly indicated by the quartz replacement of feldspar. The evidence of quartz replacement in the intermediate zone may indicate that granophyric interstices in the mixed rocks also originated through replacement.

SUMMARY AND CONCLUSIONS

The Precambrian igneous rocks in the Wichita Mountains of southwestern Oklahoma comprise a stratiform complex in which intrusions of granophyre cross-cut and overlie anorthosite and gabbro. The complex probably forms horizontal sheet-like intrusions.

Between the gabbro and granophyre a narrow zone of "intermediate rock" composed of leucogranogabbro, granogabbro, granodiorite, leucosyenogabbro and syenogabbro exhibit peculiar mineralogical and textural characters. Field occurrences and petrographic studies indicate that these rocks originated as alteration products of the gabbroic rocks through contact action of a granophyric melt. The nature of the contact effects and patterns of injection of granitic materials in the gabbroic rocks are of great variety in detail, but they may be regarded as variations of injection of distinct granitic veinlets, disintegration of gabbro in granophyre, and chemical processes, i.e., diffusion of granitic materials in gabbroic rocks.

The field relations clearly indicate that the transformation of anorthosite into leucocratic mixed rocks (leucogranogabbro and leucosyenogabbro) and gabbro into melanocratic impregnated rocks (granogabbro and syenogabbro) was largely due to percolating magmatic fluids thoroughly permeating the invaded rocks by contact action. Where the contact action has gone so far a mass of rock has become more granitic than gabbroic, leading to the development of granodiorite.

Finally, the association of the layered gabbroic intrusions and granophyre with an "intermediate zone" in the area studied is in common with those of Bushveld, Duluth, Pigeon Point, Sudbury, North Wisconsin and other complexes of the world, and the granophyre is thus presumably not just an entirely fortuitous later granite intrusion but has some genetic connection with the gabbroic rocks.

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THE BRADY SOIL AND SUBDIVISION OF POST-SANGAMONIAN TIME IN THE MIDCONTINENT REGION

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ABSTRACT. The Bradyan interglacial interval is recognized as the most significant break in sedimentation in the Midcontinent region during post-Sangamonian time. Correlation of the deposits of this interval with those of the Upper Mississippi Valley Wisconsin is still tenuous and debatable. Therefore, a provincial classification of post-Sangamonian time into Scandian, Bradyan and Almenan sub-Ages, is proposed for use in the Midcontinent region.

INTRODUCTION

The Brady soil, recognized 10 years ago as a significant entity in the late Pleistocene deposits of the Midcontinent (particularly, Kansas and Nebraska) by the application of a formal name (Schultz and Stout, 1945), has come to have an important bearing on stratigraphic and time classification. The Brady soil clearly represents the most important break in sedimentation recorded in the late Pleistocene (post-Sangamonian[1]) strata of Kansas and Nebraska; it marks the position of a distinct faunal discordance; and it has presented a challenging problem of correlation with the glacial succession of the Upper Mississippi Valley area. The physical existence, character, and extent of this buried soil (or paleosol) have been described at length (Condra and Reed, 1950; Frye and Leonard, 1951; 1952; Schultz and Stout, 1945; 1948; Thorp, Johnson, and Reed, 1951), and the field evidence will not be reviewed here. It is rather our purpose to (1) consider the various correlations that have been made with the so-called standard glacial succession of the Upper Mississippi Valley (Condra and Reed, 1950; Frye, 1951; Frye, et al., 1949; Frye and Leonard, 1951; 1952; Leonard, 1951; Ruhe, 1952a; Schultz, Lueninghoener, and Frankforter, 1951; Schultz and Stout, 1945; 1948), (2) review some of the evidence bearing on these correlations, and (3) propose a provincial time classification for the post-Sangamonian of the Midcontinent region (fig. 1).

IMPORTANCE OF BRADYAN INTERVAL

The conclusion that the Bradyan interval is a distinctive unit of time which demands recognition within the sequence of post-Sangamonian events in the Central Great Plains region is supported by several lines of evidence.

Stratigraphic evidence consists primarily of the Brady soil which is developed in the uppermost part of the Peoria loess and overlain by Bignell loess in the northwestern quadrant of Kansas, in southwestern Nebraska, and in the thick loess sequence that forms the bluffs of the Central Missouri River Valley. Morphologically the Brady soil is well developed (Frye and Leonard, 1952; Thorp, Johnson, and Reed, 1951) and demands for its formation a significant interval of time—a period of essential stability with little sedimentation or erosion. This soil is also known to occur in a sequence of alluvial deposits (Frye and Leonard, 1952; Schultz and Stout, 1948).

[1] In general, the stratigraphic nomenclature used is that of the Kansas Geological Survey (Frye and Leonard, 1952).

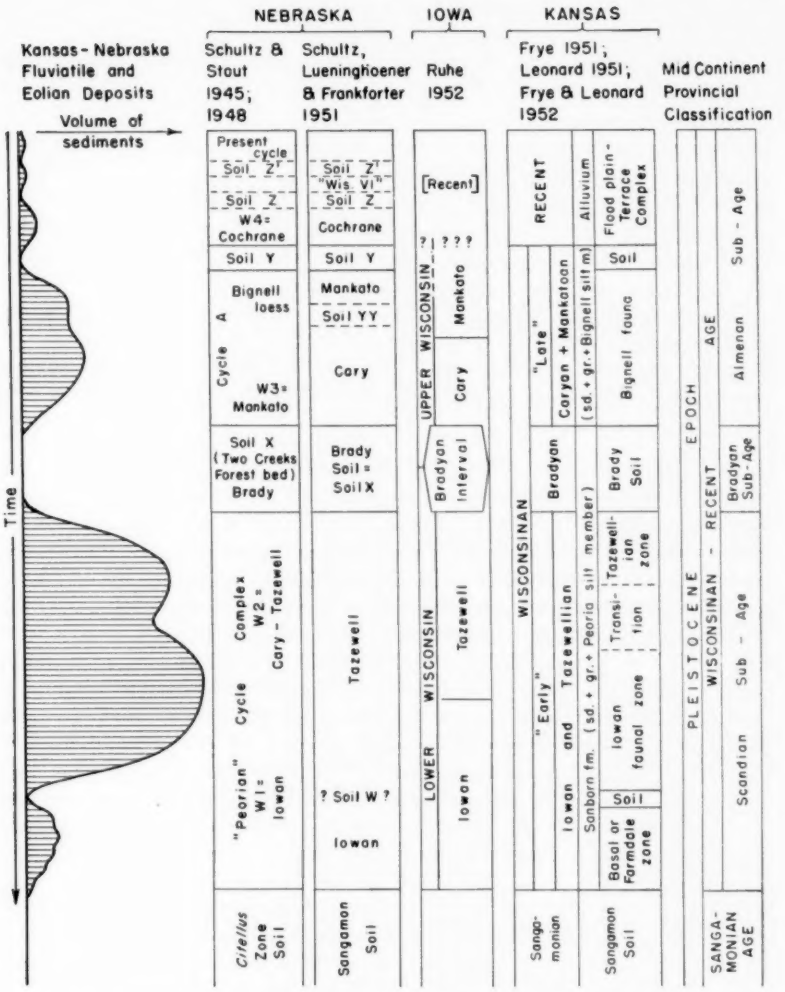

Fig. 1. Graph showing rate and volume of sedimentation in the Central Great Plains, plotted against an assumed uniform time scale. The columns to the right show recent correlations from the Great Plains and Central Missouri Valley with the Upper Mississippi Valley sequence.

Physiographic evidence of the Bradyan interval is best displayed in southern Kansas, beyond the area extensively mantled by upland loess deposits. Here, deposits firmly dated as post-Sangamonian and pre-Bradyan underlie the surfaces of terraces, with deposits equally well dated as post-Bradyan underlying the surfaces of adjacent but lower and less extensive

terraces. This relationship is interpreted as indicating an episode of Bradyan erosion in some minor valleys of extreme southern Kansas.

Equally strong, and of greater regional extent, is the paleontological evidence of this interval. The discordance in the fossil molluscan faunas across this unconformity is certainly as striking as any recorded in the three preceding major interglacial intervals. Dramatic extinction characterizes the faunal discordance across the Bradyan interval, as more than three-fourths of the species present in the pre-Bradyan Wisconsinan sediments disappeared from the Midcontinent while only four new migrants entered the region after Bradyan time. The species that disappeared from the Midcontinent during the Bradyan are still lacking in the modern fauna.

In summary, the Bradyan interval serves to divide the post-Sangamonian deposits of the Central Great Plains—well beyond the limits of Wisconsinan glaciers—into two dissimilar units (fig. 1). The molluscan faunas suggest that ecological conditions approaching those of the present have obtained in this region since Bradyan time.

REGIONAL CORRELATION

The subdivision of the Wisconsin Glacial Stage has been a major problem of glacial geology during the past half century. In the Upper Mississippi Valley region of Illinois, Iowa, Minnesota, and Wisconsin is displayed the most intricate and complete sequence of Wisconsinan moraines known on the North American Continent and it is logical that glacial geologists have turned to this area for a standard classification of the Stage. The classification most widely used in recent years is that proposed by Leighton in 1933 (also, Leighton, 1931) consisting of four sub-Stages, in ascending order Iowan, Tazewell, Cary and Mankato, to which was added in 1950 (Leighton and Willman) the Farmdale sub-Stage below the Iowan. As studies of the late Pleistocene non-glacial deposits have proceeded in the Great Plains and Missouri basin region during the last decade there have been repeated attempts to correlate the age of these deposits with the sequence of the Upper Mississippi Valley. Some of these are shown in figure 1. These suggested correlations have led to the use of time-stratigraphic terms in one region based on type localities in the other, and more recently to the projection of radiocarbon dates from one to the other on the basis of supposed or tentative correlations.

Detailed stratigraphic studies of the post-Sangamonian deposits have so far not been made across Missouri. In Iowa, Ruhe (1950; 1952a; 1952b) has used several criteria for correlation eastward but has relied for regional correlations primarily on erosional topographic discontinuity (Ruhe, 1952b, p. 49).

In Kansas, the placement of the age of the Bradyan between the Tazewell and Cary of Illinois was based on (1) correlations of stratigraphic units northeastward with the exposures in western Iowa; (2) the supposed shortness of the intervals separating the Iowan and Tazewell, and the Cary and Mankato substages; (3) the firm stratigraphic correlation of the Sangamon soil, and overlying Basal or Farmdale zone of the Peoria, across the entire region and

particularly with the type section of the Loveland loess in western Iowa; and (4) the firm faunal correlations of the Plains loess with the Peorian of Iowa and Illinois, and the zone correlations of the upper Peoria of Kansas (Leonard, 1951, p. 330; 1952) with Tazewell loess in Illinois. The fauna from Creve Coeur, Illinois used for this faunal zone correlation was collected from loess dated as younger than the Shelbyville Moraine (personal communication, M. M. Leighton) and therefore distinctly within the Tazewell sub-Stage. A review of the precision of these intra-Wisconsinan correlations from Great Plains to Mississippi Valley is prompted at this time by the progressive interregional spread of the use of the term Brady soil and the seeming anomaly of some radiocarbon dates recently reported (Suess, 1954).

At the outset it should be remembered that the type localities of the Tazewell and Cary occur in northeastern Illinois and that they are based on a sequence of glacial end-moraines, whereas the type locality of the Brady soil (from which the Bradyan interval takes its identity) is located in the loess bluffs of the Platte River Valley, near North Platte, in southwestern Nebraska —where sedimentation was controlled by mountain glaciers rather than by continental glaciers of that age. It should also be kept in mind that while the depositional history shown in figure 1 is judged to be rather well established for the Great Plains region, it was primarily influenced by glacial events in the Rocky Mountains which possibly were not synchronous in detail with glacial events in the Upper Mississippi Valley region.

In order to establish stratigraphic synchrony, comparable evidence must be available at both ends of the line of correlation, and it is equally axiomatic that the type locality must be accepted as establishing the basis for the use of any term. Opportunity was afforded for examination of the type area of Tazewell-Cary differentiation by a field conference conducted by M. M. Leighton and H. B. Willman in June, 1953. In brief, it was demonstrated that the differentiation of these two substages was based upon the intersection, or discordant relations, of end-moraines (implying ice reorganization only); that there is but a slight change in erosional topography or in degree of development of surface soils from one to the other; and that no stratigraphic evidence is known to indicate a significant period of weathering between the two. Furthermore, fossil molluscan faunas have so far not been obtained near the margin of the type Cary from stratigraphic positions known to be within either the Cary or Tazewell.

These facts destroy the value of the inferred greater brevity of the Iowan-Tazewell and Cary-Mankato intervals for correlation of Bradyan with the Tazewell-Cary interval, and raise serious doubt concerning the value of contrasting *erosional* topographies as a basis for correlation with the *type* Tazewell-Cary interval. Even though the interregional correlation of the Sangamon soil seems firm, this does nothing more than place a floor beneath the Wisconsinan as a whole. Detailed tracing of end-moraines may produce firm correlation westward from these Illinois types, but if this has been accomplished with a degree of precision to be wholly satisfying it has yet to appear in the literature.

We are seemingly left with a paleontological correlation from Creve Coeur, Illinois, to Kansas. However, on examining this correlation critically it becomes evident that, no matter how firm the correlation of the faunas, it still does not adequately answer the question. Although the Illinois locality is known to be distinctly younger than the Shelbyville moraine it is not known how much younger, and as a molluscan fauna is not known from the type Cary an upward limit has not been established. It is possible to state from the evidence in hand that the Brady soil, and therefore the Bradyan interval, is, in terms of the Illinois section, significantly post-Shelbyville.

PROPOSED TIME-STRATIGRAPHIC CLASSIFICATION FOR MIDCONTINENT REGION

In view of these relationships it is our judgement that it has hindered rather than promoted understanding of regional time relationships to project Upper Mississippi Valley sub-Ages into the Midcontinent. The same may be said of the eastward projection of the term Brady or Bradyan. Both cases imply a degree of firmness in the correlations that does not exist. The essential factors that must be considered in the erection of time-stratigraphic classification in the Midcontinent are: (1) The firm correlation of the Sangamon soil and Sangomonian Age between the two regions—therefore a modified classification involves post-Sangamonian time only; (2) sedimentation in the Plains proceeded almost continuously from the close of Sangamonian time until the initiation of the development of the Brady soil, with only minor interruptions evidenced in the upper part of the Basal (or Farmdale) zone of the Peoria silt and a change of rate about midway; (3) the firm establishment of the period of development of the Brady soil—the Bradyan interval—as a significant gap in sedimentation marked by weathering and local erosion; and (4), after the Bradyan interval, a series of pulses of sedimentation of progressively diminishing magnitude (fig. 1), separated by short intervals of little or no deposition and evidenced by immature buried soils and minor local erosion.

A provincial classification is designed to serve only the particular region involved and the foregoing considerations are best served in the Midcontinent by a threefold subdivision of post-Sangamonian time. The following sub-Age divisions of the Wisconsinan-Recent Age are suggested for provincial use in the Midcontinent without regard for correlation with other regions and without regard for the general acceptance of Recent as an Age or Epoch term.

Scandian sub-Age is suggested as a time-stratigraphic and time term to designate the interval from the end of Sangamonian to the beginning of Bradyan. The type locality of the time-stratigraphic unit is the section (NW ¼, Sec. 5, T. 3 S., R. 4 W.) of fossiliferous silt, 40 feet thick, resting on Sangamon soil developed in thin Loveland silt that overlies the Cretaceous Greenhorn limestone, in the bluff of the Republican River Valley north of the town of Scandia, Republic County, Kansas (Frye and Leonard, 1951, fig. 4; Swineford and Frye, 1951).

Bradyan sub-Stage was first proposed by Leonard in 1951 (p. 331) and based on the Brady soil which was named by Schultz and Stout (1945; 1948) from exposures in the loess bluffs south of Platte River Valley south of Bignell,

Nebraska, (Sec. 3, T. 12 N., R. 29 W., Lincoln County). It is here suggested as the second sub-Age of the Wisconsinan-Recent Age, to include the interval of time consumed in the development of the Brady soil.

Almenan sub-Age is suggested as the third and youngest time-stratigraphic and time unit of post-Sangamonian time, to include the time from Bradyan to the present. The name is derived from the vicinity of Almena, Norton County, Kansas, which is the type area of the Almena terrace (Frye and A. R. Leonard, 1949; Frye and A. B. Leonard, 1952) of Prairie Dog Creek Valley. In this area a post-Bradyan terrace is well developed, containing in the upper part of the deposits a buried soil comparable in stratigraphic position and development to soil Y of Nebraska terminology (Schultz and Stout, 1945; 1948). Also, the Almena terrace has been incised by Prairie Dog Creek with the development of a younger flood plain, and thus much of the post-Bradyan alluvial history is recorded in this vicinity. Although the upland, or loess phase of the Almenan is not well exposed at Almena, the Brady soil and overlying Bignell loess is exceptionally well exposed upstream along Prairie Dog Creek Valley in a series of road cuts north of the town of Norton.

It is to be hoped that future work will produce sufficiently precise and firm interregional correlations to permit the abandonment of provincial sub-Age units and the use of a standard subdivision of post-Sangamonian time over much if not all of the continent.

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ESSAY REVIEWS

The Ocean Floor; by HANS PETTERSSON. P. xv, 181; 48 figs. New Haven, 1954 (Yale University Press, $3.00).—Dr. Pettersson's book presents the Silliman lectures delivered at Yale University in 1952, and as remarked by the author, the ocean floor constitutes a topic admirably suited to the purpose laid down by the donor in honor of Mrs. Hepsa Ely Silliman: "to illustrate the presence and providence, the wisdom and goodness of God, as manifested in the natural and moral world."

The sea floor can scarcely be considered an isolated topic, and the author briefly discusses the inferred history of the oceans (chaps. 1, 2), bottom waters and their movements (chap. 9), and life in great depths (chap. 10), in conjunction with his central theme, the methods of investigating the nature, stratigraphy, and geochemistry of the sediments of the ocean floor (chaps. 3-8).

Dr. Pettersson is to be congratulated for the eminent role he and his collaborators have played in the exciting new investigations of the ocean floor. In his review of previous attempts and his account of the preparations for the Swedish "Albatross" expedition of 1947 the author reveals the truly international character of oceanic investigation, assays the vast cost involved, and, while generously applauding all previous investigators, scarcely omits an opportunity to remind us of the united effort made by practically the whole Swedish nation toward success of the "Albatross" cruise.

Employing Kullenberg's ingenious piston coring tube, which can produce undisturbed sediment cores up to 65 feet in length, the "Albatross" expedition obtained a remarkable collection of bottom samples from the Atlantic, Pacific, and Indian Oceans, and the Mediterranean Sea. The techniques employed in taking, storing, and studying the cores will serve as a model for similar future efforts. Though studies of the cores are still in progress, Pettersson summarizes the first published results, the doctoral dissertation of Gustaf Arrhenius, geologist of the expedition, dealing with the East Pacific samples. Arrehenius' work comprises a notable contribution to knowledge of oceanic bottom stratigraphy and chemistry.

In addition to presenting descriptive material on methods, configuration of the ocean bottom, and nature of bottom sediment, the author discusses numerous problems of marine geology. As Pettersson's points of view contrast with those of many other investigators, discussion of a few such problems seems in order.

Pettersson's central concern with the value of taking long sediment cores and the study of bottom stratigraphy and geochronology seems to have aroused in him great apprehension of the possible effect of turbidity currents on bottom sediment layers, apparently generated by some unnamed extremist(s) of Kuenen's theory, who contend(s) that possible reshuffling of bottom sediment layers by turbidity currents renders the collection of long cores useless. Whereas turbidity currents may reshuffle material deposited on submarine slopes, they perhaps do not cause any great havoc with strata on the ocean floor where these currents deposit their sediment load. Further, deposits made by turbidity currents constitute phenomena of essential contemporaneity which rank in value with volcanic ash falls as time markers in bottom stratigraphy.

Though it is true that turbidity current deposits upset calculations on the rate of deep sea sedimentation, many of the problems left unsolved, or for which other explanations are favored by Pettersson, might be enlightened by invoking turbidity currents: e.g., transportation of coarse debris and shallow-water fossils into deep water, lack of uniform vertical distribution of radioactive materials observed in some cores, and appearance of turbulent water at different depths well above the bottom. Pettersson favors action of lateral currents which erode sediment from submarine ridges as the explanation of this turbulence. Doubtless erosion and transport of mud by such currents can account for the turbulence; if so a correlation should exist between the depth of the ridges and depth of the turbulence. Turbulent water should also be restricted to lee-current sides of the ridges, unless a reversal of currents over the ridges is postulated. Turbidity currents of low density spreading out over a denser level of the stratified oceanic waters seems an equally admissible explanation of the observed turbulence.

The age of the deep ocean basins is another topic of general interest considered briefly by the author. Pettersson sets down two billion years as a conservative estimate for the age of the oceans (p. 21) and reverts to this figure when analyzing the significance of seismically determined sediment thicknesses and in estimating rates of sedimentation (chap. 4). In the opinion of the reviewer, the treatment given this important subject is somewhat superficial and disorganized. Maps showing land bridges across present oceans (figs. 6 and 7) and illustrating Wegener's hypothesis of continental drift (fig. 8) are included with no suggestion in the accompanying legends that the author regards them with suspicion, though this view is expressed in the text. Wegener's theory is finally dimissed on page 61, but one would scarcely suspect the author's view from the "Birth of the Atlantic Ocean" map (fig. 3, p. 17). The reviewer suggests that the age of the deep ocean basins ought to be held in abeyance pending further investigations, rather than be taken as the basic assumption against which all calculations must be made to agree. Perhaps the seismic evidence on sediment thickness and extrapolations from known rates of sedimentation prove instead that the deep ocean basins are not such ancient features after all, in spite of the other geophysical evidence on composition of the crust under oceans. Surely Pettersson's remark concerning the thinness of sediment found in other oceans than the Atlantic, that: "They cannot well indicate a *lesser* age of the oceans in question" (p. 61) ought to be re-examined with the lesser age possibility in mind. Until more conclusive evidence is in hand concerning rates of sedimentation, effect of compaction, and possible metamorphism of sediments on the sea floor, and until more accurate measurements of their true thickness are made, the reviewer wonders why an equally plausible alternative hypothesis is summarily discarded in favor of Dana's theory of permanence, especially in light of recent evidence of great subsidence within the Pacific basin in the Cenozoic (Ladd et al., 1953).

Abyssal red clay is another subject of repeated concern to Pettersson. One may well imagine that submarine volcanism could be important in dissolving the calcium carbonate of *Globigerina* ooze to form abyssal red clay,

as urged by Pettersson. Red clay formed by this means should show a distribution governed by proximity to sources of acid solutions from volcanic outbursts. On the other hand, acids of volcanic origin on the scale suggested by the author (p. 146) might possibly be widely toxic to organisms living in great depths.

Schott's (1935) discovery of the interstratification of red clay containing cold water species of foraminifera with *Globigerina* ooze containing warmer water species seems to substantiate the hypothesis that at least some red clay in tropical latitudes was generated during Pleistocene cold periods. As pointed out by Pettersson, this hypothesis associates formation of red clay with times of more widespread cold bottom currents, therefore presumably eliminating the possibility of pre-Pleistocene red clay. On the basis of his discovery of red clay at the bottom of a core 15 meters long from the central Atlantic, Pettersson rejects Schott's explanation. Using Schott's (1935) estimate of about 1 centimeter per 1000 years for the rate of deposition of red clay, and multiplying by the length of the core, Pettersson arrives at the venerable age estimate for the clay of 1.5 million years, which places it well below the base of the Pleistocene, assuming the conventional 1 million years for the length of the Pleistocene. For this reason Pettersson rejects the cold seas hypothesis. This discovery may well modify Schott's hypothesis. On the other hand it may indicate: (1) the duration of the Pleistocene may be more than 1.5 million years; (2) the assumed rate of sedimentation may be in error or inadequate for extrapolations; or (3) cold bottom currents may have existed during pre-Pleistocene time, even if the Pleistocene is 1 million years long and Schott's estimate is accurate for such extrapolations. None of these figures is adjusted for compaction. One wonders why Pettersson, after accepting Schott's figures, presents without comment Kröll's results (chap. 8, p. 118-120) which suggest a rate of 1 to 2 millimeters of red clay per 1000 years, in which an attempt is made to determine the time factor by direct radioactive measurements. Kröll's figures differ from Schott's estimate by a factor ranging from 5 to 10.

In the opinion of the reviewer this book could benefit by certain reorganization of material and would be more useful to geologists if certain of the theoretical discussions were treated more rigorously. The book contains much information of value to oceanographers, geologists, and others concerned with the oceans, however, and constitutes a handy guidebook to the organization of a sea-going scientific expedition which is especially concerned with study of the ocean floor.

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JOHN E. SANDERS

Science and Civilisation in China, Vol. I, Introductory Orientations; by JOSEPH NEEDHAM with the research assistance of WANG LING. P. xxxviii, 318; numerous illustrations, tables, and two folding maps. New York, 1954 (Cambridge University Press, $10.00).—When a distinguished biochemist in one

of the world's great universities undertakes to present the history of science and civilization in China, one may expect a modest result. To make this deduction in the case of Joseph Needham would be a mistake. Seldom in the history of writing can knowledge have been drawn from so many diverse sources or can more effort have been devoted to marking out the paths along which it has come. For the present, however, the reader is bemused with a prefatory work entitled *Introductory Orientations* while tantalized by the tables of contents of six volumes to follow. These will include, first, a *History of Scientific Thought*, which apparently is a summation of the classic Chinese philosophies and religious concepts, plus a consideration of certain fundamental ideas relating to science and law. The next four volumes can be indicated by their subtitles—*Mathematics and the Sciences of the Heavens and the Earth; Physics, Engineering and Technology; Chemistry and Industrial Chemistry;* and *Biology, Agriculture and Medicine*. The final tome is called *The Social Background* for which the subheadings suggest more concern with intellectual notions than with empirical considerations of Chinese behavior.

Beyond doubt, the reviewer who has the temerity to make judgments based on tables of contents puts himself in the position of a small furry animal which is nibbling cheese in a mousetrap. This predicament cannot be completely avoided, however, for it is not possible to judge a first volume of a single work fairly without considering it as a whole. Thus in the spirit of our times, we shall continue under threat of the taut wire spring, trusting that we shall not hear the snap which consigns us to ultimate rest.

On the first page of his preface Professor Needham makes clear that his purpose is to survey scientific contributions in Asia from the earliest times, giving primary attention, reasonably enough, to the Chinese. The word *Civilisation* has been added to the title, it would seem, not as something to be set off from *Science*—although in these days one might wonder—but to indicate the sweep of his interests. A survey of the special subjects of which he will treat in the future volumes shows a sophistication about science unusual among scientists. Little has been left out. As for *Civilisation*, one cannot say the same, for there is no equivalent coverage of the data on the social sciences, literature, or art.

To return to the prolegomenous first volume, we find a beautifully printed quarto of 356 pages with wide margins. Money has not been spared in the bookmaking. Chinese characters have been used in the footnotes, and the covers, which unfortunately tend to warp, have cloth specially imprinted with portraits of Taoist Genii. Inside, 160 pages are devoted to prefatory and supplementary matters, about 20 to a geographical introduction, 75 to a summary of the history of China, and 100 to early relations between that country and Europe.

As one begins the somewhat arduous journey through this volume, it may be well as a precautionary measure to be inoculated against irritation—an irritation many may not feel and others may absorb if anticipated. For example, this author has a sense of his destiny, for having reviewed the ideal qualifications for the task he has set himself, he states " . . . I have been prepared to sacrifice much in order to accomplish the survey proposed, fearing

that it might well be some time before the same collocation of circumstances recurs in another person" (p. 6). This concern for the good while in search of the true is a continuing characteristic. As he says, " . . . many of the most reliable sinologists have been extremely careless in their use of scientific terms, even when they understood them" (p. 6). This is a little frightening to those of us who, if we willingly attribute our own mistakes to carelessness, nonetheless expect our scientific colleagues to be concerned with the more impersonal problem of validity. The section ends (p. 9) with a one-page essay on thoughts stemming from a consideration of his work as a contribution to international understanding; having hoped that it will be, we are glad to move on.

We then come to eight pages of acknowledgments, a subject which ordinarily needs no review but in this case is highly significant, for it proves to be mostly autobiography. There are the charming stories of the first meeting with three Chinese friends and the message transmitted by the daughter of the Nanking pharmacist, of cycling in the rain to read the Kuan Tzu with the eminent Gustav Haloun (p. 10, 150), and of the romantic circumstances of coming upon ancient alchemical works. It thus appears that for about twenty years, including four spent meeting scholars and collecting books in China during the war while on a British cultural and scientific mission, the author prepared himself for his task.

Finally we come to a mention of Mr. Wang Ling of Academia Sinica and Trinity College, Cambridge, whose name is conspicuous on the title page. The paragraph begins with the sentence, "Mr. Wang and I both feel that it may be desirable here to explain something of the nature of the assistance which he has contributed over more than seven years." One might reasonably think so, but the curious reader is left somewhat uncertain since the stated activities of Mr. Wang seem for the most part unseparated from those of the author. Indeed, the lack of clarity suggests an injustice which Mr. Needham, out of a sense of generosity, may have done himself.

Continuing on, we come to a *List of Those who have kindly read through Sections in Draft* of the early volumes and who are thanked for their criticisms. This seems notable by reason of the fact that there are 65 names listed, many of distinguished authorities in different countries. The preface ends with a page listing formal lectures by the author with appreciation extended for the invitations to give them.

The *Plan of the Work* pulls away in an exciting start but soon runs on to a siding for a discussion of technical data pertaining to the three bibliographies and to the romanization of Chinese characters. It is possible that the machinery of understanding would prove quite as effective with less reinforcement of the scholarly apparatus. How many of the educated people to whom the book is specifically addressed will appreciate the substitution of Chhun Chhiu for Ch'un Ch'iu, or better recognize the pronunciation of the great T'ang dynasty by having it printed Thang, is uncertain. For the ordinary scholar, the Needham orthography looks silly and can be confusing in a momentary but reiterative way. Despite the numerous efforts to facilitate reference to sources, one can still suffer irritating delays. For example, if a reader, momentarily forgetting the meaning of the symbols "TH" while ab-

sorbed on page 97, attempts to find the explanation, what can he do? A search through the list of abbreviations does not help. At last, by turning backwards leaf by leaf and exploring the footnotes, he discovers the answer in one on page 75.

Continuing our survey of the book, we find a not very sophisticated 15 pages on the Chinese language but an interesting shorter section on *Bibliographic Notes*. Then come the summaries of geography and history. These can be read at the pleasant speed of a slow freight upbound on a grade. The *Geographical Introduction* is largely summarized from G. B. Cressey and Li Ssu-kuang. As Needham himself states, the writing level changes from descriptions on a relatively superficial level to something not so, as, for example, this neat technical nodule:

"Greatest of all the latitudinal fold-zones is the Chhinling mountain chain [3], which may be said to begin in the Khunlun mountains [10] of Tibet, and to die away in the east at the edge of the central north-south geanticline. The Chhinling Shan comprise a great mass between the Shensi (Kuanchung) block to the north and the Szechuan block to the south. Finally, the Nanling mountains [35], though much broken up and disturbed by subsidiary folding, divide off the southward-looking Kuangtung amphitheatre (no. 16) from the main Neo-Cathaysian Geosyncline" (p. 64).

Again in the historical sections one is flagged down by Needham's indirect innuendo that a critical friend has praised the histories by C. P. Fitzgerald, Richard Wilhelm, and Carrington Goodrich as the "least bad" books on the subject (p. 73), or such statements as: "Wieger's *Textes Historiques*, if only on account of its bulk which gives it the air of a mine of information, is at first attractive to the Western student; but for those without any knowledge of Chinese it can be really dangerous . . . . " Should anyone miss the point, a footnote adds, "Wieger's translations are very tricky . . . . " (p. 75). This type of criticism continues on the next page: "The German translations of Pfizmaier, however, are as dangerous . . . . " Some 74 of Pfizmaier's articles spread out like arsenic on four pages of Needham's bibliography. This reviewer suspects that those for whom Pfizmaier might really be dangerous are long since dead, and that most of the weaknesses of Wieger are obvious if one can only read French.

Leaving these trivia behind, it becomes quite clear as one proceeds that, besides making good use of the sources mentioned above along with many others, the real praise goes to Chi Ch'ao(now Chhao)-ting (p. 114). This emphasis suggests a coterie of scholars such as K. A. Wittfogel and O. Lattimore, and they too are obviously appreciated by Needham. In short, there is marked bias to the summary but not an unscholarly one.

The last and largest section of the text, *Conditions of Travel of Scientific Ideas and Techniques Between China and Europe*, is a major contribution in itself for it is definitely more than the complex summarizing and criticism that have preceded. Needham's genius for seeing broad vistas of space is not subverted by pretensions to a knowledge of Arabic. There are stimulating discussions of technical innovations and their spread, which in the end demon-

strate that over a vast period of time, China gave more than she received. Certainly the educated public should be pleased with this section.

In conclusion, quite apart from the author's ever insistent and critical perfectionism, we have a volume showing infinite effort devoted to a large domain. The scientific emphasis on material facts does not hide a latent idealism, nor does a scholarly devotion to coherence and correspondence conceal the strong authoritarian quality of the epistemology. It is worth a reader's submission if the author has achieved a security in the first volume to go on to the greater revelations which can be expected in those fields where Mr. Needham is most happily at home. CORNELIUS OSGOOD

REVIEWS

The Aim and Structure of Physical Theory; by PIERRE DUHEM. Translated by PHILIP P. WIENER, with a Foreword by LOUIE DE BROGLIE. P. xxii, 344. Princeton, 1954 (Princeton University Press, $6.00).—Duhem's book *La Théorie Physique: Son Objet, Sa Structure*, published in 1906, is one of the classics in the philosophy of physical science. Far from being merely analytic and purely technical, it combines an eminent scientist's insight with seasoned philosophical and historical wisdom, and it presents an account of the method of science which is at once scholarly, incisive and readable. The author had some very definite views in political and religious matters; they distinctly color his story, lending it authenticity and vivacity as well as a pleasantly human flavor. Charming and noteworthy is his exposition of the national distinction between French and British scientists, a psychological study which, had it come after Hitler, would probably incur condemnation by anthropologists. Here it adds character to the treatise and stands unobjectionable as an interesting commentary on the history of modern science.

Professor Wiener is to be congratulated on his choice of book for translation and for a job well done. HENRY MARGENAU

Die Mineralfunde der Schweizer Alpen; by ROBERT L. PARKER. P. vii, 311; 130 figs., 34 pls., including 2 folded panoramic views and a map in 4 colors. Basel, 1954 (Verlag Wepf & Co., Swiss francs 36.-, DM 34.60).—This is a revised and considerably expanded new edition of volume 1, part 2 from *Die Mineralien der Schweizeralpen* by P. Niggli, J. Koenigsberger, and R. L. Parker (1940), now out of print. The increase of about 50 percent justifies the statement that this is actually more than merely a new edition of a section of an old book. Professor Parker has retained the arrangement of his locality-descriptions by petrogenetic provinces; however, he has considerably developed the idea of "typical groups" of minerals likely to be associated in (A) granitic rocks, (B) gneiss and schists, (C) Ca-, and Mg-rich silicate deposits [characterized by titanite, epidote, prehnite, zeolites, or by talc and serpentine], (D) sedimentary and metamorphosed limestones and dolomites, (E) miscellaneous. Each of these classes is subdivided into two or more sections which are designated throughout the book by symbols like A3, etc. This is truly a scholarly compendium of the mineral localities of

the Swiss Alps; would that there were comparable books outlining similarly the same data for other regions of the world for which comparably abundant data are available.

HORACE WINCHELL

Geology and Water Resources of Garrett County; by T. W. AMSDEN, R. M. OVERBECK, and R. O. R. MARTIN. Maryland Department of Geology, Mines, and Water Resources Bull. 13. P. xiii, 349; 24 figs.; 11 pls. Baltimore, 1954.—Since 1945 Garrett County, Maryland's westernmost county and "panhandle," has been prey to a host of geologists and engineers. The Maryland Department of Geology, Mines, and Water Resources in cooperative projects with the U. S. Geological Survey and Bureau of Mines investigated the coal, refractory clay, and water resources and completely remapped the county both topographically and geologically. The maps and the reports on the coal and clay have been published. Bulletin 13, the concluding publication on the County, treats the stratigraphic and structural geology, ground water, and surface water.

In the first of three sections the geology of the county is ably presented by Thomas W. Amsden of the Department of Geology, Mines, and Water Resources who, with the aid of Robert M. Overbeck, did most of the geologic mapping. In addition to his descriptions of the outcropping formations, Amsden summarizes what is known of the subsurface strata from deep well records; the combined studies include a stratigraphic section extending from the Silurian Tuscarora formation to the Permian Dunkard group. In the second section of the Bulletin, R. M. Overbeck, also of the Maryland Department, presents a study of the ground-water resources, describing the water-bearing formations and the nature and occurrence of the ground water. Robert O. R. Martin of the U. S. Geological Survey presents the third section on the surface-water resources. The bulletin, like its predecessors in the recent Maryland series, is a handsome publication as well as a competent one.

KARL M. WAAGÉ

Autotrophic Micro-Organisms; edited by B. A. FRY and J. L. PEEL. P. xi, 305; illustrated. New York, 1954 (Cambridge University Press, $5.00).—This volume is a collection of papers read at the Fourth Symposium of the Society for General Microbiology which was held in London in April 1954. The subject under discussion is those micro-organisms which utilize carbon dioxide as their chief or only carbon source. These organisms derive their energy either from the absorption of light or from the oxidation of inorganic compounds such as hydrogen, ammonia, sulfur, and ferrous salts. Van Niel has shown that a strict definition of "autotrophic" and "heterotrophic" is impossible; we must be content to consider organisms which primarily fix carbon dioxide or which primarily dissimilate organic compounds.

In recent years we have learned much concerning the mechanism of photosynthesis, while other autotrophic modes of life have received less attention than they deserve. Biologists can therefore be grateful to the Society for General Microbiology for sponsoring a symposium which treats autotrophy

in the proper perspective: a fundamental biological problem, of which photosynthesis is only one specialized facet. Accordingly the book deals with a number of fascinating bacteria which most contemporary textbooks either ignore or dispose of in a few highly misleading sentences.

The symposium opens with a paper by D. D. Woods and J. Lascelles, entitled "The No Man's Land between the Autotrophic and Heterotrophic Ways of Life," in which the general characters of various autotrophic organisms are discussed. The authors make many illuminating comparisons and distinctions between organisms commonly classed as autotrophs and heterotrophs, emphasizing that no fundamental biochemical differences, apart from mechanisms of energy utilization, exist between the two classes. This chapter should therefore have been titled "Everyman's Land," rather than "No Man's Land."

K. A. Bisset and J. B. Grace point out that the major groups of autotrophic bacteria are pseudomonads or chlamydobacteria, while other autotrophs are probably colorless counterparts of blue-green algae. Their arguments are well taken and are independent of their contention that the pseudomonads represent a "primitive" group. This reviewer is disturbed by their attempts to locate *Thiovulum* among the protozoa.

The physiology of the Thiobacillus group is discussed by K. Baalsrud whose extensive experience with these organisms has enabled him to write an authoritative and informative chapter. Since the nitrifying bacteria are difficult to culture, less is known about them than about other autotrophic bacteria. It is therefore especially gratifying to find two chapters devoted to these organisms, one by J. Meiklejohn on their general physiology, and the other by H. Lees on their biochemistry. Dr. Meiklejohn's account, in addition to much valuable information, unfortunately also includes, uncritically, some references to work of questionable validity. Even more regrettable is her statement that autotrophs must be among the earliest forms of life. Biologists have for some time abandoned this notion, since it has become obvious that organisms which require only carbon dioxide to synthesize all organic matter are biochemically most complex, and not primitive in any sense.

Nitrogen fixation and other aspects of nitrogen metabolism in the blue-green algae are the subject of a chapter by G. E. Fogg and M. Wolfe, followed by a chapter on nitrogen metabolism in the green algae by P. J. Syrett.

H. Gaffron has undertaken the difficult task of presenting present-day views on the mechanism of photosynthesis. In this chapter not only does he present the evidence that has been gathered from work on green plants and algae but also attempts to reconcile the various and often contradictory interpretations which investigators have put forth.

The experiments of H. Larsen have done much to revive interest in the green sulfur bacteria. His present account of the green and purple sulfur bacteria should go far in stimulating further work. Another aspect of the metabolism of purple bacteria, their ability to utilize organic compounds, is discussed by S. Elsden. He also includes some very recent experiments on the participation of cytochromes in the photo metabolism of these organisms.

Almost all photosynthetic organisms contain other pigments in addition to the chlorophylls. L. R. Blinks describes the role of some of these accessory pigments, phycobilins and carotenoids: some plants which possess them may greatly extend their spectral range of photosynthesis.

Our continuous search for new sources of energy and organic raw materials, prompted by the threatened exhaustion of fossil photosynthetic products, has directed attention to autotrophic micro-organisms as possible agents for the production of organic matter on a commercial scale. E. C. Wassink discusses the practical as well as fundamental problems encountered in the culture of algae on a mass scale. The difficulties which arise in attempts to produce dense populations in a short time provide, incidentally, an insight into the competition for light and space among photosynthetic plants in general. K. R. Butlin and J. R. Postgate conclude the symposium with a well-balanced survey of the economic importance of autotrophic organisms in general, including the activities of marine photosynthetic plankton on whose activities the entire fertility of the oceans depends. The authors justly criticize Rabinowitch for his statement to the effect that the activities of chemoautotrophs are "of no consequence" today.

Although, regrettably, almost no mention is made of hydrogen bacteria and *Clostridium aceticum*, the volume contains much of the information on autotrophic organisms available today. It is quite obvious, however, that we still know very little about the autotrophic bacteria and that much remains to be added to the studies which were so brilliantly initiated by Winogradsky in 1885.

Like the previous volumes of this series the book is attractively bound and printed, but the lack of an index is a serious shortcoming.

WOLF VISHNIAC

French Bibliographical Digest: Science, Geology (2). P. 102. New York (The Cultural Division of the French Embassy, 972 Fifth Avenue, N. Y. 21, free of charge).—Geologists interested in foreign geology and in the international exchange of ideas will welcome this useful Bibliographical Digest of French geological books and articles published from 1948 to 1954. It is part of a new series of Bibliographical Digests planned to cover recent publications in all fields of French science. To date, digests covering Biology, Geography, and Geology have been published, and those for astronomy and for mineralogy, geophysics, and paleontology will be available shortly. An earlier series was published shortly after the last war to help bridge the gap in scientific liaison caused by the war; unfortunately most of the volumes, including that for Geology and Paleontology, 1940-1948, are out of print.

The pamphlet under review was prepared by Prof. Louis Glangeaud, well known for his contributions to areal and structural geology, and he has contributed an 11-page summary of the trends in French geology represented in the Digest. For most of the nearly 450 books and articles listed in the pamphlet there is a short paragraph summarizing the content or conclusions. As the articles are arranged by subject, it is easy for each geologist to turn to those subjects that interest him, and he will inevitably find several im-

portant references that he must look up—when he can find the time. There is an author index, a list of French periodicals, societies, and government agencies that publish geological articles, and a list of French publishers and of bookstores in the United States that handle French publications. The Digest is distributed free of charge to institutions and scientists, as a public service, by the Cultural Division of the French Embassy in New York.

JOHN RODGERS

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Greenwich Photo-heliographic Results, 1944. London, 1954 (Her Majesty's Stationery Office £1 0s 0*d*).

Introduction to Theoretical Mechanics; by R. A. Becker. New York, 1954 (McGraw-Hill Book Company, $8.00).

Petroleum Microbiology; by Ernest Beerstecher, Jr. Houston, 1954 (Elsevier Press, $8.00).

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U. S. Geological Survey Water-Supply Papers as follows: 1137-I, Summary of Floods in the United States During 1950 ($ .20). 1186, Quality of Surface Waters of the United States, 1950, Parts 1-4, North Atlantic Slope Basins to St. Lawrence River Basin ($1.50). 1188, Parts 7-8, Lower Mississippi River Basin and Western Gulf of Mexico Basins ($1.50). 1191, Water Levels and Artesian Pressures in Observation Wells in the United States in 1951, Part 1, Northeastern States ($1.25). 1246, Surface Water Supply of the United States, 1952, Part 12, Pacific Slope Basins in Washington and Upper Columbia River Basin ($1.25). 1300, The Industrial Utility of Public Water Supplies in the United States, 1952; by E. W. Lohr and S. K. Love ($1.75). 1301, Compilation of Records of Surface Waters of the United States through September, 1950, Part 1-A, North Atlantic Slope Basins, Maine to Connecticut ($1.75). Washington, 1954.

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